Macroeconomic Risk in Exchange Rates: three empirical essays

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Contents

List of Figures

List of Tables

Chapter 1

Macroeconomic risk in exchange rates: three empirical essays

Macroeconomic risk in exchange rates: three empirical essays

Rahel Studer

Abstract

This introductory umbrella chapter interlinks the three essays of this dissertation thesis and explains their stance towards the economic discipline. The essays focus on two key exchange rate puzzles, which are the forward premium puzzle of Fama (1984) and the consumption real exchange rate correlation puzzle of Backus and Smith (1993). As regards the first puzzle, this thesis explains the surprisingly predictable currency returns as a hedge of macroeconomic risk. The first essay argues that the cross-sectional distribution of consumption among OECD countries explains currency returns, and the second essay highlights the Swiss franc, which is a safe haven currency and therefore particularly driven by global risk. The third essay proposes that consumer prices within the Eurozone behave conforming to standard macroeconomic theory thus attenuating the puzzle of Backus and Smith. The three essays of this thesis present reduced form empirical models and interpret results taking guidance from state-of-the-art structural models. Such baseline models generally fail to precisely generate the observed patterns in the data. But being aware of this, this thesis demonstrates how powerful these simple models nevertheless are to understand empirical correlations.

1.1 Macroeconomic risk in exchange rates: three empirical essays

Two puzzles

Two key exchange rate puzzles motivate the essays of this dissertation thesis: the *forward premium puzzle* of Fama (1984) and the related *carry-trade anomaly*, and the *consumption real exchange rate puzzle* of Backus and Smith (1993) and Kollmann (1995). Both puzzles refer to empirical observations that are surprising from the perspective of international macroeconomic models: contrary to what standard theory predicts, high interest rates and high consumption growth are often not accompanied by exchange rate depreciations. The first essay entitled *Systematic Consumption Risk in Currency Returns*[1] interprets surprisingly high carry-trade returns, which currency investors can expect, as a compensation for global macroeconomic risk. An example of a currency that is particularly driven by such global risk is the Swiss franc which the second essay entitled *The Swiss franc's honeymoon*[2] focuses on. The third essay entitled *Not that puzzling – consumption and relative prices within the EMU*[3] contrasts relative consumption growth rates and relative inflation rates of Eurozone countries and observes that within this country group, the consumption real exchange rate puzzle is not pertinent: as theory predicts, Eurozone countries with high consumption growth tend to have low inflation and thus depreciating real exchange rates. In the following, this introductory umbrella chapter presents the two exchange rate puzzles and summarizes how the three essays of this thesis explain them.

The forward premium puzzle and the carry-trade anomaly

The first puzzle, Fama's (1984) forward premium puzzle, roots in the assumption that the forward premium corresponds to the market-determined expected depreciation of a foreign currency, plus a risk premium,

$$f_t - s_t = E(s_{t+1} - s_t) + \psi_t.$$

The forward premium — the difference between forward exchange rates (f) and spot exchange rates (s) — equals the difference between countries' risk-free interest rates

[1] Hoffmann and Suter (2013)
[2] Studer-Suter and Janssen (2014)
[3] Rahel Studer, August 2016, unpublished manuscript

if covered interest rate parity (CIP) holds; typically, CPI holds. Surprising is that in empirical tests, the forward premium usually points in the wrong direction for ex post movements in the spot exchange rate: high forward premia (or high interest rates) predict appreciating foreign currencies. Hence, investors can expect profits from borrowing in low-interest-rate-currencies and investing in high-interest-rate-currencies. This implies that the currency market risk premium ψ in the above equation must be large, predictable, and more volatile than the forward premium itself.

To measure and eventually explain the currency market risk premium ψ with a macroeconomic model, I define that ψ equals expected carry-trade returns, that is, the gap between currencies' interest rate differentials and their expected appreciation. In empirical tests, interest rate differentials usually predict carry-trade returns. Hence, any variable that determines differences between expected carry-trade returns across currencies also explains variance occurring in risk premia. A model for this risk premium is Solnik's (1974) international version of the Sharpe (1964) and Lintner (1965) capital asset pricing model (CAPM) in which the risk premium is proportional to the covariance of assets' expected returns with state variables that capture global market risk. Global risk, or systematic risk, refers to gains or losses which investors cannot hedge.

Systematic consumption risk in currency returns

The first essay of this thesis entitled *Systematic consumption risk in currency returns* follows Lustig et al. (2009) who notice that the carry-trade profit earned from investing money borrowed in currently low-interest-rate-currencies into currencies paying currently high interest rates qualifies as a slope factor for currency returns. In the CAPM framework, this implies that the return of this interest rate based carry-trade strategy mirrors global market risk. Our essay follows this approach, but introduces a carry-trade factor that bases on the cross-sectional distribution of consumption growth. While doing so, we take guidance from the consumption-based capital asset pricing model (CCAPM) where the covariance of currencies' value with global consumption booms and busts predicts returns. We show that countries' past consumption growth predicts currency returns with almost the same accuracy as interest rates. Further, our consumption-based carry-trade return obtained from borrowing in low-past-consumption-growth currencies and investing in high-past-consumption-growth currencies explains cross-sectional differences in currency returns. In particular, high-past-consumption-growth currency portfolios appreciate on average but depreciate whenever global carry-trades are low and indicate "bad times". In return, investments in low past consumption growth portfolios provide a hedge against global market risk.

Ever since the seminal contribution of Fama and French (1989), it has become standard in asset pricing to explain the return of portfolios build along assets' characteristics which predict returns. Applied to currency returns of consumption growth or interest rate sorted portfolios, this approach also embeds the recent proposal of Hassan and Mano (2015) regarding the carry-trade anomaly: rather than a time-series phenomenon, carry-trade returns probably should be assessed in the cross-section whereby currencies with constantly high consumption growth or interest rates pay high expected returns. In this context, I interpret consumption growth sorted portfolios as synthesized assets or synthesized countries with constantly high or low consumption growth that pay high or low returns depending on the state of the global economy at a particular date.

The Swiss franc's honeymoon

The second essay of this thesis entitled *The Swiss franc's honeymoon* focuses on a currency with a conspicuous status in the international carry-trade: while paying low interest rates and low returns on average, the Swiss franc appreciates whenever international market risk increases. An approved measure for such international market risk is the Chicago Board Option Exchange's index of implied volatilities of option contracts on the S&P 500 market index, the VIX. This global risk variable strongly correlates with the Swiss franc/euro exchange rate, which highlights the safe haven property of Swiss franc denominated assets. Accordingly, the Swiss franc appreciated sharply in the wake of the global financial crisis of 2008/2009 and the subsequent European sovereign debt crisis, when the VIX was high and volatile. Because it started to severely challenge the Swiss economy, the Swiss National Bank attempted to halt this unchecked appreciation by lowering interest rates, expanding the monetary base, and eventually declaring a minimum exchange rate of the Swiss franc to the euro of 1.20 in September 2011.

The safe haven property of the Swiss franc together with the Swiss National Bank's policy stance form the stage for a macroeconomic model for the exchange rate. In particular, the essay retrieves the base model of Krugman (1991) that describes the behavior of exchange rates within target-zones. In Krugman's exposition of the model, exchange rates are a function of money demand shocks (velocity shocks). For the Swiss franc, we measure these demand shocks by the VIX-global-market-risk fundamental. This implements the risk-based save haven explanation of Swiss franc returns described above. The key prediction of Krugman's model is that the Swiss National Bank's commitment to always prevent the Swiss franc from appreciating beyond 1.20 to the euro mutes the sensitivity of the franc to the VIX also at levels well above 1.20. This obtains because markets expect that the central bank will ultimately intervene if the exchange rate threatens to surpass its lower bound. We conclude that the Krugman (1991) model describes the Swiss franc/euro exchange rate well during the lower bound regime over September 2011 to January 2015. First, the sensitivity of the Swiss franc/euro exchange rate to the VIX-index declines as the Swiss franc approaches the lower bound. Second, currency option prices suggest that markets mostly have trusted in the Swiss National Bank's commitment to defend the 1.20 lower bound, which is crucial for the model to hold. To summarize, the Swiss franc value of the euro is driven by global market risk, but over fall 2011 to winter 2015, the sole announcement of the SNB to defend a Swiss franc lower bound has stabilized the Swiss franc.

Not that puzzling – consumption and relative prices within the EMU

While the forward premium puzzle is a short-term pricing puzzle (carry-trade profits can realize within splits of a second in over-the-counter currency markets), the second puzzle which this thesis addresses is a longer-term quantity puzzle. Different versions of the complete markets model with agents deriving utility from consumption according to constant relative risk aversion (CRRA) preferences imply a perfect correlation of consumption growth with real exchange rates: countries with comparably low consumption should have appreciating real exchange rates. Backus and Smith (1993) derived this implication in a model with segmented goods markets, but the condition also arises in various contexts whenever the law of one price fails. From the perspective of these models, it is surprising that there is only a weak correlation between relative consumption and real exchange rates which often even points into the wrong direction. From an outside perspective, the puzzle demonstrates the limits of the international macroeconomic model. This has motivated a large literature to develop rich structural models that can match the empirically observed correlations of consumption and real exchange rates. Contrary to this, the third essay entitled *Not that puzzling – consumption and relative prices within the EMU* qualifies the basic model's limits by taking a purely empirical approach. The essay starts with the proposition that nontraded goods components in final consumption baskets explain differences in price dynamics across countries, and then shows that within the Eurozone, prices of consumption goods that presumably have large nontraded shares tend to be countercyclical, as theory predicts. In a country sample with a common currency and hence a fixed nominal exchange rate, countries with currently high consumption growth tend to have falling relative prices which corresponds to a real depreciation. This pattern is significant in the panel, but a focus on the cross-section yields even clearer predictions: sorting countries into portfolios according to their consumption growth rate at each date unveils a monotone relationship between portfolios' consumption growth and their real appreciation towards the Eurozone average. Hence, the cross-sectional rank of a country's consumption growth informs about its real exchange rate.

1.2 Empirical approach of the thesis

This thesis discusses the interplay of quantity and price data over the last 25 years, a period characterized by overall growing financial markets in relatively stable market conditions, but ensued by two major crises in the USA and Europe, the global financial crisis and the European sovereign debt crisis. The thesis supports a risk-based view on currency prices and emphasizes that rather than in the time series dimension, the co-movement of consumption and prices in the panel and in the cross-sectional dimension supports long-served models' predictions.

To study the exchange rate models, this thesis choses a partial equilibrium approach. It takes allocations as given, which are in particular the consumption distribution and the market return, and assesses the adjustment of relative prices. The thesis estimates empirical reduced form models and interprets the results taking guidance from basic structural models. Throughout the thesis, key assumptions are that a stochastic discount factor exists, and that there are country-specific risk-free assets which international investors can access. Hence, complete financial markets are not a prerequisite.[4]

Reduced form models which build the backbone of this thesis describe a dependent variable, in particular relative prices, as a function of independent variables such as consumption growth or the market return, plus an error term. The first essay describes currency portfolios' return as a function of a global carry-trade factor, the second essay describes the value of the Swiss franc as a function of global market risk and the monetary policy regime, and the third essay describes the projection of relative consumption on relative prices. The estimated functional relationships are then compared to the predictions of structural models. The first essay takes guidance from a version of the Campbell and Cochrane (1999) model with external habit formation to interpret

[4] To price currency returns in the first essay, it suffices that a projection of the true discount factor on the space of traded assets exists. For the third paper, if financial markets are incomplete, the theoretical consumption real exchange rate relationship holds in expectations.

why the consumption growth path of countries matters for risk premia: low consumption growth over a prolonged period increases consumers' fear of global breakdowns and makes them require higher risk premia. The second essay argues that market expectations of the monetary authority's policy stance mutes the sensitivity of the Swiss franc to global risk without explicitly modeling expectations, and the third paper suggests that real exchange rates support risk sharing without precisely specifying preferences. An alternative, structural approach would be to test for the best fitting model that can reproduce jointly observed exchange rate and consumption growth time series. But this is not the aim of this thesis. In contrast, the reduced-form approach allows for a general assessment of the merits and limits of aspects of international macroeconomic models. The thesis finds that old, basic models, set into a modern context, make sense at an intuitive level.

1.3 Abstracts of the three essays

So far, this introduction has presented the three essays of this thesis in their overall context and has discussed their general approach. To conclude, the abstracts of the three essays provide a further overview at a glance.

Systematic consumption risk in currency returns

(with Mathias Hoffmann)

In this paper, we sort currencies into portfolios by countries' past consumption growth. The excess return of the highest-over-the-lowest consumption-growth-portfolio — our consumption carry factor — compensates for negative returns during worldwide downturns and prices the cross-section of portfolio-sorted and of bilateral currency returns. Empirically, sorting currencies on consumption growth is very similar to sorting currencies on interest rates. We interpret these stylized facts in a habit formation model: sorting currencies on past consumption growth approximates sorting on risk aversion. Low (high) risk aversion currencies have high (low) interest rates and depreciate (appreciate) in times of global turmoil.

The Swiss franc's honeymoon

(with Alexandra Janssen)

Starting from the stylized fact that the Swiss franc is a safe haven currency, this paper focuses on the determinants of the Swiss franc during the lower bound regime from September 2011 to January 2015. We describe the Swiss franc as a function of global market risk fundamentals and find that the macroeconomic model outlined by Krugman (1991) describes the EUR/CHF exchange rate well during this time. We show that, as predicted by Krugman's model, the sole expectation that the Swiss National Bank would prevent the Swiss franc from appreciating beyond 1.20 to the euro muted the sensitivity of EUR/CHF to global market risk. An important assumption for the model prediction to hold is that the central bank's commitment to the exchange rate target is credible. We thus use EUR/CHF option prices together with the global market risk fundamental to assess the credibility of the lower bound. We find that the only true credibility issue was in November 2014. After November 2014, the Swiss National Bank could convince markets anew from its target-zone policy and suspend the lower bound unexpectedly a few weeks later.

Not that puzzling – consumption and relative prices within the EMU

Monthly retail sales data and consumer price inflation support the predictions of a complete markets model with nontraded goods: within the Eurozone, countries with below average consumption growth tend to have appreciating real exchange rates. Thereby, goods that are rather characterized as nontradable across locations explain relatively larger shares of the variance of the real exchange rate between individual countries and the Eurozone, as the traded-nontraded goods model for the real exchange rate predicts. The monotone relationship between consumption growth and real appreciation is particularly clear for portfolios built along countries' consumption growth. This inspires the interpretation of exchange rate returns from an asset pricing perspective. The Backus and Smith (1993) puzzle highlights limits of the classical international macroeconomic model. This paper puts these limits into perspective.

Chapter 2

Systematic consumption risk in currency returns

Systematic consumption risk in currency returns

Mathias Hoffmann   Rahel Studer-Suter

Abstract

In this paper, we sort currencies into portfolios by countries' past consumption growth. The excess return of the highest-over-the-lowest consumption-growth-portfolio — our consumption carry factor — compensates for negative returns during worldwide downturns and prices the cross-section of portfolio-sorted and of bilateral currency returns. Empirically, sorting currencies on consumption growth is very similar to sorting currencies on interest rates. We interpret these stylized facts in a habit formation model: sorting currencies on past consumption growth approximates sorting on risk aversion. Low (high) risk aversion currencies have high (low) interest rates and depreciate (appreciate) in times of global turmoil.

JEL Classification Numbers: E44, F31, F44, G12, G15

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2.1 Introduction

In this paper, we provide evidence that currency returns reflect cross-country differences in consumption risk. We do so by sorting currencies into portfolios based on countries' consumption growth over the last four quarters. High-past-consumption-growth currency portfolios pay consistently higher excess returns than low-past-consumption-growth currency portfolios. A consumption carry factor that reflects the return of going short on currencies of low-past-consumption-growth countries and long on currencies of high-past-consumption growth countries explains the cross-section of currency returns in a sample of 29 countries over the period 1990 – 2015. We call this factor the consumption carry factor and denote it by $\text{HML}_{\Delta c}$.

In recent years, the idea that movements in currency prices can be explained by the trade-off between risk and return has gained renewed attention and considerable empirical support. At a general level, a couple of conditions need to be fulfilled for currency returns to reflect a compensation for some form of macroeconomic or financial risk. First, currencies that pay high returns on average must perform relatively badly in bad times, whereas currencies that pay low returns on average must perform well in bad times. Second, currency returns must reflect cross-country differences in the exposure to common (global) risk, because only global risk will be priced in integrated world capital markets. Lustig et al. (2011) show that currency returns are well explained by a two-factor model in which the first factor is the average return on the dollar vis-à-vis all other currencies, and the second factor is the spread in returns between a portfolio of high-interest-rate currencies and a portfolio of low-interest-rate currencies. As the latter factor, which is a carry trade factor and denoted HML_{FX}, pays off badly in crises, differences in the exposure of high- and low-interest-rate currencies to this factor can explain a substantial fraction of the variation in the cross section of interest-rate-sorted currency portfolios. Verdelhan (2011) extends this framework to the pricing of bilateral exchange rates and argues that differences in the exposure to a (level) dollar factor are also a key element of the systematic variation in exchange rates. Ranaldo and Soderlind (2010) find that so-called 'safe haven' currencies pay relatively high returns precisely when foreign exchange market volatility increases, whereas the returns from 'investment currencies' are low in times of high foreign exchange market turbulences. Menkhoff et al. (2012a) add to these findings by showing that a foreign exchange volatility innovation factor rationalizes the spread in returns of interest-rate-sorted currency portfolios. Together, all these results suggest that the returns obtained from holding particular currencies or currency portfolios compensate an investor for global market risk.

While these studies provide compelling evidence for a risk-return trade-off in foreign exchange markets, they propose financial factors as an explanation for currency returns. Hence, they do not fully answer the question whether these risk factors truly reflect macroeconomic and, in particular, consumption risk. Another strand of the literature has recently begun to address this issue. Lustig and Verdelhan (2007) argue that an extended version of the consumption-based capital asset pricing model (C-CAPM) with Epstein–Zin preferences and a durable consumption good can explain the cross section of interest-rate-sorted currency portfolios. Sarkissian (2003) explores a version of the C-CAPM with incomplete markets, finding that the cross-sectional variance in consumption growth rates helps explain currency returns. Colacito and Croce (2011) show that a version of the long-run risk model by Bansal and Yaron (2004) explains currency movements quite well, and Verdelhan (2010) shows that consumption habits can explain the cross section of currency returns. Hassan (2013) uses a model with non-traded goods to illustrate that larger countries pay lower interest rates and, by the failure of UIP, lower expected returns because they insure people's consumption against worldwide consumption shortages.

The analysis in this paper positions itself between these two strands of the literature. We follow the first strand and construct a simple pricing factor that is based on sorting currencies into portfolios according to *ex ante* observable characteristics. This approach allows us to discuss the determinants of currency returns under as few theoretical assumptions as possible — in particular, we do not have to specify strong restrictions on preferences. We follow the second strand of the literature, however, by focusing on consumption fluctuations as a driver of variation in currency returns. Linking these two approaches allows us to determine the structure of consumption risk priced into currencies directly from the data without having to confront particular moment restrictions that specific versions of the consumption-based asset pricing model may impose on the data.

Specifically, we sort currencies into portfolios based on countries' past consumption growth. Currencies of countries with higher past consumption growth consistently pay higher returns than currencies of countries with low consumption growth, and the spread in these returns is well explained by the consumption-based carry trade return factor $\text{HML}_{\Delta c}$, which equals the difference in returns of the high and the low-consumption-growth currency portfolios.

In its ability to price exchange rates, the consumption carry factor $\text{HML}_{\Delta c}$ compares favorably with a range of financial risk factors that have recently been proposed, notably with the interest rate carry factor HML_{FX} proposed by Lustig et al. (2011). $\text{HML}_{\Delta c}$ is also successful in pricing the interest-rate-sorted currency portfolios used elsewhere in the literature. In addition, we show that $\text{HML}_{\Delta c}$ also prices individual currency pairs in a framework in which individual currency betas vary as a function of past consumption growth.

It is *not* our objective in this paper to argue that $\text{HML}_{\Delta c}$ outperforms extant financial pricing factors. Consumption is much more infrequently and noisily measured than financial variables such as interest rates. Hence, *a priori* we would not expect a factor that is based on measured consumption to outperform financial factors. Bearing this in mind, we argue that it is still a very interesting exercise to see how far we can go by sorting on measured consumption growth instead of interest rates. Our contribution, therefore, is to establish a novel stylized fact: information about past consumption growth helps price currency returns and it does so almost as well as information embodied in interest rates: sorting currencies on interest rates is practically equivalent to sorting them on past consumption growth and $\text{HML}_{\Delta c}$ prices currency returns practically as well as HML_{FX} .

To understand this stylized fact, we find it instructive to take guidance from a consumption based model with habit formation in the mold of Campbell and Cochrane (1999) and Verdelhan (2010). In this model, consumption is the true source of variation in national discount factors. But the model also implies that sorting currencies on past consumption is equivalent to interest rates, consistent with what we find in the data. These features make the habit model an attractive starting point for understanding why cross-country differences in past consumption growth matter for currency returns.

In a model with habit formation, sorting currencies on past consumption growth is very similar to sorting countries by their surplus consumption ratio and, therefore, by their degree of risk aversion. Countries that recently have experienced a series of high (low) consumption growth rates have high (low) surplus consumption ratios and therefore a low (high) degree of risk aversion. In complete financial markets, exchange rate changes are determined by differences in countries' marginal utility growth . Because, in the habit model, marginal utility in high-risk-aversion countries is more sensitive to global consumption shocks than in low-risk-aversion countries, optimal risk sharing requires that currencies of countries with high (low) risk aversion appreciate (depreciate) in times of global downturns, transferring purchasing power to the more risk averse country. This implies that the high average returns paid by currencies with high past consumption growth compensate investors for the risk of a large depreciation during global downturns. When interpreted in the context of the habit model, our $\text{HML}_{\Delta c}$ factor therefore reflects the spread between the return of low- and high-risk-aversion currencies. Because higher (lower) risk aversion leads to higher (lower) precaution and therefore to lower (higher) interest rates, in this model, sorting currencies on past consumption growth is therefore akin to sorting on interest rates. We show that a realistically calibrated version of the habit model with a global consumption growth shock can broadly replicate the empirical findings that we present in the main part of the paper.

The paper is organized as follows. The next section further connects our empirical approach and the previous literature. Section 3 defines currency returns and discusses the formation of portfolios based on past consumption growth. Section 4 describes the data set used in the empirical analysis, and Section 5 presents the empirical results. In Section 6, we interpret our empirical results in the context of a version of the Campbell and Cochrane (1999) habit model. Section 7 presents an overview of some robustness checks, and Section 8 concludes.

2.2 Related literature

Starting with Fama (1984), a large literature has documented the resounding rejection of uncovered interest parity (UIP) in the data. In fact, there is considerable structure in this rejection: currencies of countries with high interest rates do not depreciate as much as would be implied by UIP. This UIP puzzle, along with the finding by Meese and Rogoff (1983) that exchange rates are hard to predict out-of-sample, gave rise to a large empirical literature on exchange rate modeling. It is probably fair to say that much of this early literature was rather skeptical with respect to risk-based explanations of currency returns. Engel (1996) and Lewis (1995) provide useful surveys. During the last decade, the notion that currency returns, just like those of other assets, could be determined by risk premia has gained renewed attention and — probably because of the availability of more, better and larger data sets and theoretical advances in asset pricing theory — is continuing to gather empirical support.

A valid explanation of the UIP puzzle in terms of risk premia would require that investment in currencies with high interest rates — which promise high returns on average — would deliver especially low returns in bad times for investors. If this was the case, carry trade profits would just compensate an investor for risk that he exposes himself to when holding particular currencies. Empirically, however, it is challenging to identify risk factors, and especially macroeconomic risk factors, that would drive currency risk premia.[1]

[1] Burnside et al. (2011a) find that traditional risk factors do not explain currency returns and attribute the forward premium to peso problems.

In this respect, an important contribution is the study by Lustig and Verdelhan (2007). As interest rates seem to predict currency returns, Lustig and Verdelhan sorted a wide cross section of currencies into portfolios according to their interest rate differentials with the US. Portfolios are rebalanced every period such that the first portfolio always contains the lowest-interest-rate currencies and the last portfolio always contains the highest-interest-rate currencies. Sorting currencies into portfolios eliminates currency-specific components of returns such that sharp estimates of the risk–return trade off of currency investments are obtained. Eventually, Lustig and Verdelhan (2007) show within the framework of consumption-based capital asset pricing models that the growth rate of durable and nondurable consumption expenditures, as well as the mean return of the US stock market, are helpful in explaining currency portfolio returns.

In a subsequent study, using a data-driven approach in the spirit of Fama and French (1993), Lustig et al. (2011) find that the currency portfolios themselves contain information to explain the cross section of portfolio returns. Lustig et al. (2011) identify two factors that together account for most of the variability in the cross section of currency portfolio returns. The first factor, which they coin the 'dollar risk factor', is the average return that an investor gains by borrowing in US dollars and investing in equal weights in all currencies available. This dollar-specific factor acts as a level factor for portfolio returns. The second factor equals the return that a global investor gains by going short in the low-interest-rate currency portfolio and long in the high-interest-rate currency portfolio. Lustig et al. (2011) denote this carry trade factor HML_{FX} . While profitable for most of the time, such a carry trade strategy yields low returns during times of global turmoil, which implies a negative HML_{FX} factor. As expected returns increase monotonically from low to high interest rate currency portfolios, and because the covariation of portfolio returns and HML_{FX} is higher, the higher the interest rates of a particular currency portfolio are, HML_{FX} qualifies as a slope factor for currency portfolio returns. Closely related to these results, the study by Menkhoff et al. (2012a) concludes that a factor that measures news in global foreign exchange market volatility decisively explains the returns to carry trades. High expected carry trade returns can be rationalized within standard asset pricing models, because these returns turn especially low during times of high foreign exchange market volatility surprises when investors particularly fear losses. Brunnermeier et al. (2008) uncover another link between the performance of carry trades and market volatility. According to their reasoning, a sudden increase in stock market volatility (as measured by the CBOE's VIX) could cause a decrease in risk appetite and funding liquidity, which then makes investors unwind their carry trades. An orchestrated sellout of investment currencies depreciates their prices all the more such that unexpectedly low returns to carry trades are realized. In accordance with this interpretation, Ranaldo and Soderlind (2010) find that currency market volatility has a nonlinear effect on currency returns. In particular, Ranaldo and Soderlind show that it takes a high currency market volatility to affect, for example, the CHF/USD exchange rate, but exchange rate reactions are then particularly strong. Christiansen et al. (2011) demonstrate that the exposure of currency returns to the US stock and bond markets varies as a function of foreign exchange market volatility. Mancini et al. (2013) show that liquidity is a priced factor in currency returns.

Our paper is related to a number of recent studies that have started to link the carry trade to observable macroeconomic fundamentals. Jorda and Taylor (2009) show that the profitability of currency carry strategies can be improved by using macroeconomic conditioning information such as deviations from purchasing power parity. Their fundamental carry strategy leads to a higher Sharpe ratio and less negative skewness of returns relative to the conventional carry strategy. Nozaki (2010) reports similar results for a fundamental strategy in which the investor goes long in currencies that are undervalued relative to some simple model of the equilibrium exchange rate and short in overvalued currencies. Such an investment strategy leads to a much lower Sharpe ratio than the typical carry trade strategy, but it outperforms carry trades in times of high market turmoil. Habib and Stracca (2011) examine what country characteristics determine the safe haven status of a currency. In a large cross section of developed and emerging economies, they find that the only variable that robustly predicts whether a particular currency is a 'safe haven' against global volatility risk is a country's net foreign asset position. Hassan (2013) observes that it is large economies that systematically pay low interest rates leading to persistent violations of UIP. He interprets this stylized fact using a model with non traded goods, in which large countries' bonds endogenously are better hedges against global consumption risk than small countries' bonds because they insure a larger fraction of world consumption against idiosyncratic consumption slumps.

Our analysis is also closely related to Menkhoff et al. (2012b) who sort currencies into portfolios based on a range of macroeconomic fundamentals, such as past GDP growth, past money growth or the deviation from a Taylor rule. They find that past macroeconomic fundamentals have significant predictive power for currency returns. Our approach is similar in that we sort on a particular macroeconomic characteristic — past consumption growth. However, different from Menkhoff et al. (2012b), we use spreads between high consumption growth and low consumption growth portfolios as a pricing factor.

Hence, while a number of studies document a role for macroeconomic fundamentals in explaining momentum or predictability in currency returns, none of them has moved on to examine the pricing power of such fundamentals-based risk factors. Also, to our knowledge, none of these papers have used business cycle frequency movements in consumption as conditioning information in constructing such a carry factor, as we do here. As our results are obtained without particular restrictions on preferences (as is usually the case in consumption-based asset pricing models) they provide independent evidence that the heterogeneity in past consumption movements is priced into currencies.

In the next section, we present a foreign exchange investment strategy that is directly based on the cross-sectional distribution of consumption growth rates. This allows us to unveil a direct link between patterns of international consumption co-movement and returns to investment in the foreign exchange market.

2.3 Forming currency portfolios based on past consumption growth

This section first introduces notation concerning currency returns. Then, we discuss how to form currency portfolios based on cross-country differences in past consumption growth rates. Eventually, we introduce the consumption-based carry trade factor $\text{HML}_{\Delta c}$ and discuss its statistical properties.

2.3.1 Currency returns

From the perspective of a US investor, the gross excess return of investing into the currency of a foreign country k is given by

$$RX_{t+1}^{k} = \frac{(1+i_t^k)}{(1+i_t^{US})}\frac{S_t^k}{S_{t+1}^k} \tag{2.1}$$

where S_t^k denotes the current spot price of one US dollar measured in units of currency k and i_t^k denotes the one-period risk-free rate of interest in currency k at time t. An increase in S_t^k indicates a depreciation of currency k against the US dollar. Except in times of high market turmoil and at very high frequencies (see for example Baba et al. (2012)), covered interest rate parity holds such that the interest rate differential between two currencies equals the forward premium,

$$F_t^k(1+i_t^{US}) \quad = \quad S_t^k(1+i_t^k). \tag{2.2}$$

F_t^k denotes the forward price of one US dollar to be delivered in period $t+1$ measured in units of currency k. Taking logs and substituting equation (2.2) into equation (2.1) yields the following approximate equation for currency returns[2]

$$\begin{aligned} rx_{t+1}^k &= i_t^k - i_t^{US} - \Delta s_{t+1}^k \\ &= f_t^k - s_{t+1}^k \end{aligned} \tag{2.3}$$

where, henceforth, $rx_{t+1}^k = RX_{t+1}^k - 1$ denotes the (net) excess return on investment in currency k. This is the return that a US investor obtains from buying currency k in the spot market today and selling it forward. Under uncovered interest parity, rx_{t+1}^k should be equal to zero in expectation. However, the failure of the uncovered interest rate parity relationship has been documented widely in the literature: currencies that trade at a forward discount, i.e. currencies that pay higher interest rates than a given base currency because $f_t^k - s_{t+1}^k > 0$, typically do not depreciate as much as would be implied by uncovered interest rate parity. Hence, borrowing in low-interest-rate currencies and investing in high-interest-rate currencies generates positive expected excess returns. Conversely, currencies that trade at a forward premium tend to generate negative expected returns. The observation that expected returns from currency investment are not zero forms the point of departure for the analysis in this paper. We argue that positive expected currency returns compensate investors for systematic cross-country differences in consumption risk.

2.3.2 Consumption growth sorted currency portfolios

Portfolios formed with respect to past consumption growth rates reveal a stable pattern in currency excess returns: currencies of countries with higher past consumption growth promise higher excess returns than currencies of low-consumption-growth countries, and, while relatively high on average, carry trades that borrow in low-consumption-growth currencies and lend in high-consumption-growth currencies perform especially

[2]Using forward prices instead of interest rate differentials to calculate currency excess returns has a number of advantages. In particular, problems concerning the correct matching of maturities for interest differentials are avoided. Also, the forward returns are implementable at rather low trading costs, and investors hardly expose themselves to counter-party risk (King et al. (2011)).

poorly during times of global turmoil when investors might particularly fear losses.

At the beginning of each new quarter, we sort currencies into n portfolios based on the associated countries' consumption growth rate over the preceding four quarters, such that the first portfolio always contains currencies of countries with the lowest n-tile of past consumption growth rates, and the last portfolio always contains currencies with the highest n-tile of past consumption growth rates.

Table (2.1) shows descriptive statistics for $n = 5$ portfolios formed out of a sample of OECD countries over the period from 1990 to 2015. A detailed description of the data follows in the next section, and details on the composition of the portfolios are given in the Appendix. Average returns increase with average past consumption growth. The table shows that investment in the portfolio of the highest-consumption-growth countries yields average annual returns of about 2.9 percent, whereas the portfolio of currencies of the lowest-consumption-growth countries only yields an annual return of -0.3 percent. High-consumption-growth portfolios also have higher Sharpe ratios than low-consumption-growth portfolios. These results suggest that cross-country differences in past consumption growth are an indicator of the differences in the risk exposures of currencies.

The key element of asset pricing is that there are states of the world in which investors particularly fear losses. We argue that a factor that indicates that such bad states have occurred is given by the difference between the return of the high-consumption-growth portfolio and that of the low-consumption-growth portfolio. Hence, this factor — which we refer to as $HML_{\Delta c}$ or as the 'consumption-carry factor' — is the cross-country average return that a global investor obtains when she borrows in the currencies of countries with the world's lowest consumption growth and invests in the currencies of countries with the world's highest consumption growth.

The last column of Table (2.1) shows that this carry trade returns of 3 percent a year, with a Sharpe ratio of 0.25. The empirical analysis of the next section will reveal that this $\mathrm{HML}_{\Delta c}$ factor explains the cross-sectional difference in expected portfolio returns to a considerable extent and that it is globally priced.

The second last column of Table (2.1) shows descriptive statistics for $\overline{\mathrm{rx}}$, which is the average return that an investor achieves by borrowing at the beginning of each quarter in US dollars and investing in equal weights into all currencies available in the sample over a holding period of one quarter. Lustig et al. (2011) call this factor the 'dollar risk factor', because it captures the idiosyncratic (country-specific) component of an investment strategy that funds itself in dollars and goes long in the cross section of all other currencies. At each point in time, the dollar risk factor therefore essentially captures the average rate of depreciation of the dollar against all other currencies. As this dollar factor is important for the level of all dollar-denominated returns, it is important to include it in all our pricing exercises below. However, because of its country-specific nature, we do not expect that this US dollar factor can explain the cross-sectional difference in the returns of different currency portfolios. As argued by Lustig et al. (2011), it should therefore not be globally priced. This means that there should be no differences across currency portfolios in the exposure to this factor.

Conversely, we will show in the next sections that the $\text{HML}_{\Delta c}$ factor is globally priced — that is, we will show that it prices the cross section of currencies exactly because currency portfolios have different degrees of exposure to it.

A couple of remarks on the procedure for sorting currencies into portfolios based on past consumption growth rates are in order. First, it is important to recognize that, over time, currencies change portfolios, reflecting countries' changing position in the cross-country distribution of consumption growth rates. This is the essence of forming portfolios: the fact that individual currencies may change portfolios reflects the fact that they may not have a fixed exposure to the risk that we wish to price. This may imply that individual currencies do not have a constant beta with respect to the risk factor $\text{HML}_{\Delta c}$. However, as we will show, and as has also been emphasized by Lustig and Verdelhan (2007) and Lustig et al. (2011), portfolios of currencies do have a constant beta with respect to the risk factor $\text{HML}_{\Delta c}$.[3]

Second, we focus on consumption growth over the past four quarters to build currency portfolios, instead of consumption growth rates at the highest available (i.e. quarterly) frequency. This reflects the recent focus of the literature on the role of low- to medium-frequency components in consumption for asset pricing. For example, quarterly consumption data might be a very noisy measure of true consumption, so that averaging consumption growth over several periods could provide a better approximation of the ultimate consumption risk that investors care about.[4] Alternatively, investors might have

[3]Note that the approach of building portfolios is also robust to missing data: for some countries, available consumption series do not span the whole sampling period, for other countries, forward exchange rates became available only in the late 1990s, and euro countries are excluded from the sample after they introduced the common European currency.

[4]Within the framework of the basic consumption-based capital asset pricing model (C-CAPM), Jagannathan and Wang (2007) show that the fourth quarter to fourth quarter consumption growth rate is a powerful pricing factor, and Parker and Julliard (2005) find that the covariance of returns and consumption growth across the 25 Fama and French (1989) portfolios explains the difference in expected returns observed in the US stock market extremely well, if consumption growth is measured over the quarter of the return and many following quarters. Lettau and Ludvigson (2001) reason that consumption should

a preference for an early resolution of uncertainty, so that small but potentially very persistent movements in long-term consumption growth carry a much higher risk price than short-term fluctuations in consumption.[5] Finally, building growth rates over one year implicitly also deals with seasonal effects present in some of the consumption growth series.

2.3.3 The consumption carry factor $\text{HML}_{\Delta c}$

This section discusses the consumption carry factor $\text{HML}_{\Delta c}$ in more detail and sets it in relation to other pricing factors that have been proposed in the literature. Table (2.2) presents key statistics for $\text{HML}_{\Delta c}$, as well as for other factors: the mean return of the consumption-carry strategy is close to 3.0 percent per year, and the Sharpe ratio is around 0.25. These figures are both smaller than the respective values for Lustig, Roussanov and Verdelhan's (2011) forward-discount-based carry trade strategy HML_{FX} which, calculated using quarterly data, pays an average annual return of around 5.1 percent with a Sharpe ratio of 0.29. The correlation of the two factors is highly significant, though at 0.48 not perfect. Figure (2.1) plots $\text{HML}_{\Delta c}$ against HML_{FX} and shows that the two factors are generally very highly correlated. This is true during most periods of global turmoil such as the Euro crisis of 1992, the Mexican Peso crisis of 1994, September 11 2001 and the Bear Stearns bankruptcy in August 2007 but also during more tranquil periods. One reason why the two factors are not perfectly correlated is that they do not strongly move together during the Lehman shock in 2008, whereby the consumption-based carry trade strategy provided distinctly less volatile returns than the forward-discount-based carry trade strategy. This, however, may not be surprising: given that the consumption-based strategy is a function of consumption growth over the last four quarters, sorting on past consumption growth is much less sensitive to sudden gyrations in interest rates that occur during a global crisis than is sorting on current interest rates. Conversely, countries with sudden idiosyncratic crises (such as Island during the 2008 crisis) may have high interest rates but sudden consumption busts. Against this background and taking account of the likely noise in quarterly consumption data, it is remarkable how close sorting on past consumption growth comes to sorting on interest rates when it comes to pricing the

react predominantly to permanent shocks in wealth, such that the consumption-to-wealth ratio (cay) is unaffected. Fluctuations in cay therefore signal transitory variation in wealth (i.e. future returns), which implies that cay is a powerful pricing factor for asset returns.

[5] In the long-run risk models introduced by Bansal and Yaron (2004), consumption growth follows an ARMA(1,1) process with a slow-moving permanent component, such that shocks will affect consumption at a very long horizon. As agents dislike such long-run risk, a highly volatile consumption-based discount factor results, which has the power to explain observed asset returns.

cross-section of currencies — as we document in the remainder of the paper.

Consistent with this, $\text{HML}_{\Delta c}$ is also correlated with another return-based factor that has proven successful in pricing currencies, the global exchange market volatility factor suggested by Menkhoff et al. (2012a). Conversely, our consumption carry trade factor is virtually uncorrelated with the more traditional pricing factors motivated by the (consumption based) CAPM, such as world average consumption growth, the global stock market returns as measured by the MSCI world index or the cross-country variance of consumption growth rates (Sarkissian (2003)).

2.4 The data

The data set used in this analysis includes time series for private final consumption expenditure as well as spot- and forward exchange rates for a cross-section of 29 OECD countries which are Australia (AUD), Austria (ATS), Belgium (BEF), Canada (CAD), Czech Republik (CRK), Denmark (DKK), Estonia (EEK), France (FRF), Germany (DEM), Greece (GRD), Hungary (HUF), Iceland (ISK), Ireland (IEP), Italy (ITL), Israel (ILS), Japan (JPY), Mexico (MXN), Netherlands (NLG), New Zealand (NZD), Norway (NOK), Poland (PLN), Portugal (PTE), South Korea (KRW), Sweden (SEK), Switzerland (CHF), Spain (ESP), United Kingdom (GBP), United States (USD), and the Eurozone (EUR). Quarterly consumption growth rates are sourced from the OECD national accounts database; growth rates are measured over one year, that is, consumption is compared to consumption of the same quarter of the previous year. Starting from daily midpoint quotes, spot- and three month forward exchange rates correspond to averages over the last ten trading days of each quarter. We think that this choice is robust to end-of-month effects that might be present in exchange rates on the one hand side, but does not blur variation in exchange rates on the other hand side. Our analysis however is robust to the use of daily end-of-quarter quotes or quarterly average quotes. For each country/currency, data is included in the analysis only when all, consumption growth rates, forward- and spot exchange rates are available: for some currencies, forward quotes are only available starting in the mid 1990s', whereas other countries drop out of the sample when they introduced the euro. The analysis in this paper covers the period from the first quarter 1990 to the fourth quarter in 2015. The appendix presents more details for the data.

2.5 Empirical results

2.5.1 Pricing currency returns

The price of an asset equals its expected discounted payoff. This price reflects the systemic component of risk associated with a particular asset, which is determined by its exposure to a set of common risk factors. As carry trades are a zero-net-investment strategy, if the law of one price holds, the return on each portfolio j, denoted by rx^j_{t+1}, must satisfy

$$0 = E(M_{t+1} rx^j_{t+1}) \tag{2.4}$$

where M_{t+1} denotes the stochastic discount factor that prices the payoffs denominated in US dollars. We assume that the stochastic discount factor M is linear in the pricing factors

$$M_{t+1} = 1 - b' f'_{t+1} \tag{2.5}$$

where f_{t+1} denotes a matrix of risk factors containing the different factors in its columns, and b is the column vector of factor loadings. Equation (2.4) and (2.5) imply that

$$\begin{aligned} E(rx^j_{t+1}) &= -\left(cov(M_{t+1}, rx^j_{t+1}) var(M_{t+1})^{-1}\right)\left(var(M_{t+1}) E(M_{t+1})^{-1}\right) \\ &= \beta^{j\prime}\lambda \end{aligned} \tag{2.6}$$

where the column vectors β^j contain regression coefficients that are obtained by running time series regressions of portfolio returns rx^j on the factors of the stochastic discount factor. The market price of risk λ mirrored by each factor can be estimated by running a cross-sectional regression of expected portfolio returns on β^j. Substituting the expression for the stochastic discount factor (2.5) into the Euler equation (2.4) yields the following alternative expression for the expected returns of currency portfolio j

$$E(rx^j_{t+1}) = cov(f_{t+1}, rx^j_{t+1})' b \tag{2.7}$$

where $cov(.)$ denotes the column vector of covariances of the individual elements of f with rx. Hence, the market price of risk λ and the factor loadings b are related by $\lambda = var(f_{t+1})b$ where $var(.)$ denotes the covariance matrix of f. The factor loadings b

are estimated by a cross-sectional regression of expected excess returns on the covariance between returns and factors.

Our objective is to show that $HML_{\Delta c}$ prices currency returns. We therefore specify the stochastic discount factor as

$$M_{t+1} = 1 - b_{\overline{\mathrm{rx}}} \cdot \overline{\mathrm{rx}}_{t+1} - b_{\mathrm{HML}_{\Delta c}} \cdot \mathrm{HML}_{\Delta c,t+1}$$

At this stage, our justification for this choice is purely empirical. Very much as in the case of the interest-rate sorted portfolios of Lustig et al. (2011), a high-minus-low factor appears as a natural starting point for pricing currencies, since it spans much of the cross-sectional variability in returns. Indeed, as can be seen from Figure (3.7), $\mathrm{HML}_{\Delta c}$ is highly correlated with the second principal component of the five consumption-sorted portfolio returns. This allows us to interpret $\mathrm{HML}_{\Delta c}$ as a global slope factor that determines return differences in the cross section of currency excess returns.

As a second factor, we include the return to a US investor who owns an equal-weighted portfolio of the cross section of all currencies. As shown by Lustig et al. (2011), this factor, referred to as $\overline{\mathrm{rx}}$, captures base-currency-specific (here: dollar-specific) influences on the cross section of currency returns. It is therefore a base-currency specific factor and acts as a level shifter for all dollar-denominated returns. In keeping with this notion, it is highly correlated with the first principal component of the returns on our six portfolios, see the first panel of Figure (3.7).

Time series regression

A factor mirrors global risk if differences in expected returns across portfolios can be explained by differences in the extent to which portfolios load on this factor. We obtain the loadings or βs on the risk factors $\overline{\mathrm{rx}}$ and $\mathrm{HML}_{\Delta c}$ by running the following time series regression separately for each currency portfolio j.

$$rx^j_{t+1} \quad = \quad a^j + \beta^j_{\overline{\mathrm{rx}}} \cdot \overline{\mathrm{rx}}_{t+1} + \beta^j_{\mathrm{HML}_{\Delta c}} \cdot \mathrm{HML}_{\Delta c,t+1} + \varepsilon^j_{t+1} \tag{2.8}$$

Figure (2.3) plots the estimate of $\beta^j_{\mathrm{HML}_{\Delta c}}$ for each currency portfolio j against its mean excess return. The low-consumption-growth portfolio pays the lowest returns on average, and its correlation with $\mathrm{HML}_{\Delta c}$ is relatively low: in bad times, when $\mathrm{HML}_{\Delta c}$ declines, this portfolio still performs relatively well and thus shields an investor's income stream against low returns. In contrast, the return of the high-consumption-growth portfolio covaries more strongly with $\mathrm{HML}_{\Delta c}$. Indeed, the estimates of $\beta^j_{\mathrm{HML}_{\Delta c}}$ increase almost monotonically from low- to high-growth portfolios, which implies that currencies of countries with higher past consumption growth are more exposed to risk mirrored by $\text{HML}_{\Delta c}$.

Table (2.3) presents the results from estimating equation (2.8). All portfolios but one load significantly on $\text{HML}_{\Delta c}$ while the constants (α^j) are insignificant in all regressions. The observation that portfolios of currencies of countries with relatively high past consumption growth pay relatively high returns on average, together with the finding that high-consumption-growth currency portfolios covary more strongly with the consumption carry trade factor, implies that $\text{HML}_{\Delta c}$ explains the cross-sectional difference in expected portfolio returns: high-growth-currency portfolios pay higher expected returns because they perform badly exactly when $\text{HML}_{\Delta c}$ is low, which is in bad economic times when investors are especially concerned that their portfolios do not perform badly. The dollar risk factor $\overline{\text{rx}}$ on the contrary does not account for the difference in returns across portfolios, because all portfolios load on it with a roughly equal estimated coefficient $\beta^j_{\overline{\text{rx}}}$ of about one. This suggests that $\overline{\text{rx}}$ is indeed a local factor that accounts for shifts in the average level of US-dollar denominated returns that the investor obtains from investing in foreign currencies during any given quarter.

Cross-sectional regression

While $\beta^j = [\beta^j_{\overline{\text{rx}}} \quad \beta^j_{\text{HML}_{\Delta c}}]'$ measures the exposure of each currency portfolio j to the proposed risk factors, $\lambda = [\ \lambda_{\overline{\text{rx}}} \quad \lambda_{\text{HML}_{\Delta c}}]'$ is commonly interpreted as the price of risk. In equation (2.6), λ corresponds to the ratio of the variation of the stochastic discount factor and its expected value. We follow Cochrane (2005) (Chapter 13) and estimate equations (2.6) using GMM.[6] Inference is based on a Newey and West (1987) covariance matrix estimator with an optimal lag length set as suggested by Newey and West (1994). As expected, Table (2.4) reveals that the dollar risk factor $\overline{rx}$ is not priced. The price of the consumption carry trade factor $HML_{\Delta c}$ on the contrary is significantly positive, and it amounts to 320 basis points per annum. This implies that an asset with a β of

[6] Using GMM to estimate the price of the risk factors $\lambda = (\lambda_{\overline{\text{rx}}}, \lambda_{\text{HML}_{\Delta c}})'$ implies that two sets of moment conditions are evaluated at the same time: those that generate the regressors β and those that generate the cross-sectional regression coefficients λ. In contrast to a two-pass estimation procedure, where an estimate of λ is obtained by running a cross-sectional regression of expected asset returns on the βs that were obtained previously by running time series regressions as specified in equation (2.8), using GMM has the advantage that the covariance matrix between the two sets of moment conditions takes into account that the βs are estimated coefficients as well. This leads to larger standard errors for the λ coefficient estimates.

one earns a risk premium of 3.2 percent per annum[7], and equation (2.6) indicates that currency portfolios with a higher $\beta_{\mathrm{HML}_{\Delta c}}$ pay higher expected returns.

To test whether the consumption carry trade factor $\mathrm{HML}_{\Delta c}$ helps to price the currency portfolios given the presence of the other risk factor $\overline{\mathrm{rx}}$, we focus on the asset pricing model in discount factor form given by equation (2.7). We estimate the vector $b = [\ b_{\overline{\mathrm{rx}}} \quad b_{\mathrm{HML}_{\Delta c}}]'$ together with the covariance of factors and portfolio returns using GMM. We find that the estimate $b_{\mathrm{HML}_{\Delta c}}$ is positive and significantly different from zero at the five percent confidence level, whereas $b_{\overline{\mathrm{rx}}}$ has no significant impact on the discount factor of US investors. This result confirms the conjecture that the consumption carry factor $\mathrm{HML}_{\Delta c}$ mirrors global risk, whereas the dollar risk factor $\overline{\mathrm{rx}}$ does not. It is consistent with the prediction of models in which the investor's utility is increasing and concave in consumption, which produces a high intertemporal marginal rate of substitution when consumption is low: in bad times for investors, the consumption carry trade factor $\mathrm{HML}_{\Delta c}$ is low, which together with a positive $b_{\mathrm{HML}_{\Delta c}}$ implies a high discount factor M — see equation (2.5).

Regarding the fit of the model, Figure (2.4) plots the average returns of the consumption-growth sorted currency portfolios against the returns predicted by the model. The model explains the returns of the five currency portfolios well: the p-value of the pricing error test amounts to 70%-79%, which implies that we cannot reject the null that the pricing errors from the cross-sectional regression of mean currency portfolio returns on the βs equal zero.

These results suggest that $\mathrm{HML}_{\Delta c}$ captures global risk in the world cross section of currencies. In the next section, we examine whether $\mathrm{HML}_{\Delta c}$ prices a cross section of test portfolios that have been sorted by forward discounts (as in Lustig et al. (2011)) and compare the pricing power of the consumption carry factor to that of two other extant factors, the Lustig et al. (2011) HML_{FX} factor and the Menkhoff et al. (2012a) foreign exchange volatility innovation factor, which have both been constructed from purely financial information.

[7] As the risk factor $\mathrm{HML}_{\Delta c}$ is a linear combination of the returns of two test assets, it has a time series regression β of one on itself. Hence, the price of risk λ should equal the mean of $\mathrm{HML}_{\Delta c}$, which holds true in our estimation exercise.

2.5.2 Forward discount sorted currency portfolios and further risk factors

The consumption carry trade factor $\text{HML}_{\Delta c}$ can reflect global, systematic risk in the cross-section of exchange rates only if it explains the returns on any set of currency portfolios. Initiated by Lustig and Verdelhan (2007), the most commonly used test assets in the current literature on currency pricing are forward-discount-sorted currency portfolios. The results presented in Table (2.5) suggest that the consumption carry trade factor prices this cross section of test assets as well, and that it compares favorably to other risk factors proposed by the literature.

In Table (2.5), the test assets are five currency portfolios that have been constructed for each quarter by sorting the currencies of the OECD data sample on their forward discount relative to the US dollar observed at the end of the preceding quarter. Descriptive statistics for these forward-discount-sorted currency portfolios are provided in Table (A.2) in the Appendix. Using this set of test assets, we estimate the price of the consumption carry trade factor $\text{HML}_{\Delta c}$ to be 624 basis points a year, and it is significantly different from zero at the two percent confidence level.

The second and third columns of Table (A.2) show estimates of risk prices and factor loadings for two further risk factors; namely, for the Lustig et al. (2011) HML_{FX} factor and the Menkhoff et al. (2012a) foreign exchange volatility innovation VOL factor. We have constructed both risk factors as described in the respective papers using the quarterly data of the OECD sample specified in Section (4.4). Both risk factors, HML_{FX} and VOL, are able to price the quarterly forward-discount-sorted currency portfolios.

In Table (2.6) we compare the estimated betas for the forward-discount sorted portfolios that we obtain from each of these three models. The betas on $\text{HML}_{\Delta c}$ are increasing in the forward discount and all but one of them are significant while the α^j are almost all insignificant. This is the same pattern that we obtain when we use HML_{FX} and VOL as pricing factors. This suggests that $\text{HML}_{\Delta c}$ captures much of the pricing power of these two factors also on the forward-discount sorted portfolios.

2.5.3 Horse race between pricing factors

In this section, we run a horse race between the three foreign exchange risk factors $\text{HML}_{\Delta c}$, HML_{FX} and VOL. The test assets are five forward-discount-sorted currency portfolios plus our previous five consumption-growth-sorted currency portfolios.

In Table (2.7), the panel on the left shows the estimated price of risk λ for the three foreign exchange risk factors when included jointly in the stochastic discount factor together with the dollar risk factor $\overline{rx}$. Testing for $\lambda^i = 0$ in the beta representation of the asset pricing model $E(rx^j) = \beta^{j\prime}\lambda$ amounts to testing whether the factor f^i is correlated with the true discount factor (see Cochrane (2005)). The table reveals that both carry trade factors, the consumption based carry trade factor $\text{HML}_{\Delta c}$ as well as the forward discount based carry trade factor HML_{FX}, are significantly priced when considered individually. But they are also both significantly priced when included jointly as pricing factors, suggesting that both reflect priced variation in the stochastic discount factor.

The relationship between the risk price λ and the factor loadings on the discount factor, b is given by $\lambda = var(f)b$. As the foreign exchange risk factors $f = (\overline{\text{rx}} \quad \text{HML}_{\Delta c} \quad \text{HML}_{FX} \quad \text{VOL})'$ are correlated (see Table 2.2), testing for $\lambda = 0$ does not answer the same question as testing for the joint hypothesis $b = 0$. The parameters b of the stochastic discount factor $M_{t+1} = 1 - b' f_{t+1}$ capture whether a factor is marginally useful in pricing assets, given the presence of the other factors. In Table (2.7), the panel on the right reveals that our consumption carry trade factor is a highly significant pricing factor given the dollar factor $\overline{rx}$. However, both $\text{HML}_{\Delta c}$ and the forward-discount-based carry trade factor HML_{FX} turn insignificant when included jointly into the stochastic discount factor: the correlation of HML_{FX} and $\text{HML}_{\Delta c}$ is such that it becomes impossible to distinguish their marginal contribution to M_{t+1}. Likewise, $\text{HML}_{\Delta c}$ and HML_{FX} remain significant in a pairwise comparison with VOL, but all three pricing factors turn insignificant when included jointly. These results confirm that our consumption carry trade factor $\text{HML}_{\Delta c}$, the Lustig et al. (2009) forward discount based carry trade factor HML_{FX}, as well as the Menkhoff et al. (2012a) currency market volatility factor VOL all qualify as global risk factors, whereby they suggest that these factors reflect the same kind of global risk.

To conclude, $\text{HML}_{\Delta c}$ successfully prices the cross section of consumption-growth-sorted and forward-discount-sorted currency portfolios. Thereby, $\text{HML}_{\Delta c}$ compares well with other pricing factors that have previously been suggested in the literature. We explicitly do not claim that we 'beat' these other factors. Rather, $\text{HML}_{\Delta c}$ seems to capture the same information as HML_{FX}. Importantly, however, our factor differs from HML_{FX} and other previous factors in that it is constructed based on past macroeconomic fundamentals — specifically on consumption growth rates. This suggests that international differences in medium-term consumption growth are informative with respect to the risk exposure of a country's currency to global shocks, and that they can help explain *why* HML_{FX} is successful in pricing currencies.

2.5.4 Explaining bilateral currency returns

Our results so far show that there are systematic differences in the exposure to the consumption carry factor across currency portfolios sorted on different criteria — interest rates and past consumption growth — and that these differences are priced. By contrast, individual currencies will not generally have a fixed, time-invariant exposure to the global factor: because currencies change portfolios over time, their exposure to the consumption carry risk factor $\text{HML}_{\Delta c}$ will in general be time-varying as well. However, because we observe that the expected returns of high-past-consumption-growth currency portfolios covary more strongly with $\text{HML}_{\Delta c}$ than expected returns of low-consumption-growth currency portfolios, a country's past consumption growth rate should pin down its exposure to $\text{HML}_{\Delta c}$. This reasoning allows us to price individual currency pairs using a β-representation in which the β is a time-varying function of the consumption growth differential between the country of which the US investor holds currency assets and the US. This motivates the panel regression

$$rx_{t+1}^{k} \quad = \quad \alpha^{k} + \gamma_1 (\widetilde{c}_t^{k} \text{HML}_{\Delta c,t+1}) + \gamma_2 \widetilde{c}_t^{k} + \gamma_3 \text{HML}_{\Delta c,t+1} + \gamma_4 \overline{\text{rx}}_{t+1} + \varepsilon_{t+1}^{k} \qquad (2.9)$$

where k indexes an individual country, and where $\widetilde{c}_t^{k} = \Delta c_t^{k} - \Delta c_t^{US}$ is the difference between the US consumption growth rate and the consumption growth rate of country k over the quarters from $t-4$ to t. In this specification, country k's exposure to $\text{HML}_{\Delta \text{c}}$ is given by

$$\beta^{k}(t) = \gamma_1 \widetilde{c}_t^{k} + \gamma_3$$

and therefore varies over time as a function of a country's past consumption growth. Conversely, in this regression, the term $\gamma_3 \text{HML}_{\Delta c,t+1} + \gamma_4 \overline{\text{rx}}_{t+1}$ captures effects that are common to the cross section of returns.[8]

Table (2.8) shows the results from the bilateral pricing regression (2.9). Note first that the interaction of $\text{HML}_{\Delta c}$ with past country-level consumption growth — the coefficient γ_1 — is positive and significant, whereas γ_3 is not significant. Further we cannot reject the null that the country-specific intercepts α^k equal zero jointly, the p-value obtained from an F-Test equals 0.5. These results underpin the interpretation of $\text{HML}_{\Delta c}$ as a global slope factor that explains differences in returns between currencies provided that these

[8]We include the first-order term $\gamma_2 \widetilde{c}_t^{k}$ to make sure the interaction $\widetilde{c}_t^{k} \text{HML}_{\Delta c,t+1}$ does not become spuriously significant. As we will see, this first-order term will not be significant though and all our results remain unchanged if we drop it.

countries have different consumption growth rates. As countries change their position in the cross-sectional distribution of past consumption growth rates, their exposure to $\text{HML}_{\Delta c}$ will change as well. Conversely, $\text{HML}_{\Delta c}$ does not significantly impact the average dollar-denominated return on foreign currency. This role of a level factor is, again, mainly played by $\overline{\text{rx}}$, which loads with a coefficient of virtually one on the cross section of currency returns.

To illustrate further that differences in the exposure to $\text{HML}_{\Delta c}$ explain the cross section of currency returns and that $\overline{\text{rx}}$ fully captures level shifts in dollar-denominated returns, we also estimate a version of the panel regression in which we control for time-fixed-effects, τ_t,

$$rx_{t+1}^k = \alpha^k + \gamma_1 \widetilde{c}_t^k \times \text{HML}_{\Delta c,t+1} + \gamma_2 \widetilde{c}_t^k + \tau_t + \varepsilon_{t+1}^k. \tag{2.10}$$

This panel regression displays a very similar level of fit to the pricing regression above, and the coefficients γ_1 is also very similar and significant; see Table (2.8). Again, we cannot reject that the α^k are jointly zero (p-value: 0.36). This illustrates that potentially unobserved country characteristics do not affect the results regarding the sensitivity of individual currencies with respect to the common risk factor $\text{HML}_{\Delta c}$. It is also interesting to note that the estimate of the time-fixed effect τ_t in equation (2.10) is closely linked to the dollar risk factor $\overline{\text{rx}}_t$: the correlation of the two series is literally one. This confirms that the dollar risk factor — the average return an investor gains by borrowing in US dollars and investing in all currencies available in the market — provides a level factor for the cross section of dollar returns.

Regressions (2.9) and (2.10) suggest that excess returns from currency investment are related to past consumption growth even at the level of individual currencies: because γ_1 is positive, and because $\text{HML}_{\Delta c}$ is positive on average, currencies of countries with higher than US consumption growth pay positive expected returns, whereas currencies of countries with relatively low consumption growth pay negative expected returns. However, excess returns on high-consumption-growth currencies may turn negative, and expected returns on low-growth currency portfolios may turn positive, when there is a large negative shock to $\text{HML}_{\Delta c}$, which will be the case in bad times when global stock market returns decline and consumption dispersion increases (see Table 2.2).

To emphasize that it is truly exchange rate risk that drives currency returns, and not forward discounts that are known *ex ante*, the lower panel of Table (2.8) reports results from estimating regressions (2.9) and (2.10) again, but now with nominal exchange rate changes, $-\Delta s^k_{t,t+1}$, instead of currency returns as the left-hand variable.[9] The observation that the estimate of γ_1 remains virtually unchanged corroborates our conclusion that nonzero expected currency excess returns merely compensate an investor for the exchange rate risk to which he exposes himself when holding currencies of countries with high past consumption growth that promise positive expected returns.

2.5.5 Further comparison between consumption sorted and the interest rate sorted portfolios

The analysis so far suggests that $\text{HML}_{\Delta c}$ and HML_{FX} not only behave very similar in the time series (see Figure (2.1)), but the two risk factors also seem largely equivalent in terms of pricing currency returns. Before we interpret these findings in a theoretical framework, we show that, empirically, sorting currencies on past consumption growth or on forward discounts yields very similar cross-sectional results. Figure (2.5) plots the return of each of the five consumption growth sorted portfolios together with the return of the respective forward discount sorted portfolio, whereby the deviation of each portfolio's return from the average USD currency market return, $rx^j_{t+1} - \overline{\text{rx}}_{t+1}$, is shown. For all five portfolio pairs, these portfolio-specific returns co-move quite strongly, suggesting that sorting on consumption or interest rates yields very similar returns at the level of the individual portfolio. Discrepancies between the two sorting procedures mainly occur in the period during and after the 2008 financial crisis. In that period, the lowest forward discount (lowest interest rate) currencies performed quite well, manifesting the insurance value of these currencies. In contrast, the lowest consumption growth currencies plummeted. As a consequence, the carry trade return $\text{HML}_{\Delta c}$ did not fall to the same extent as HML_{FX} during that crisis, see Figure (2.1) again. During the crisis, it was rather the portfolio with the second lowest consumption growth currencies that performed best. In Figure (A.2) in the appendix, we trace out the path of individual currencies through portfolios over time, both for the interest-rate sort and for the consumption-growth sort. As is apparent, the discrepancy between the 'low' portfolios during 2008-09 is due to countries such as Iceland or Hungary. These countries have low consumption growth and high interest rates during the crisis, implying that their currencies end up in a 'high' portfolio when sorted on interest rates and in a 'low' portfolio when sorted on consumption growth. On the other hand, typical funding currencies like

[9] As currency excess returns are given by $rx^k_{t,t+1} = f^k_{t,t+1} - s^k_{t+1} - \Delta s^k_{t,t+1}$, for the sake of comparability, we use the negative of the nominal exchange rate change $-\Delta s^k_{t,t+1}$ as the left-hand variable. Recall that $-\Delta s^k_{t,t+1} > 0$ indicates an appreciation of currency k against the US dollar between t and $t+1$.

the Swiss franc or the Japanese yen persistently fall into the low interest rate portfolio, but experienced relatively high consumption growth rates in the aftermath of the global financial crisis and during the European sovereign debt crisis. However, barring these easily interpreted differences, we think that it is striking how similar the two sorts ultimately are. We take this *de facto* equivalence of consumption- and interest-rate based sorts as an important starting point for our interpretation of the data in terms of a simple theoretical model.

2.6 Interpreting the stylized facts: a consumption habit model

We have shown that currencies of countries that recently experienced consumption booms appreciate on average, whereas currencies of low-past-consumption-growth countries tend to depreciate. This pattern reflects a compensation for global risk: consumption boom currencies depreciate strongly in times of global distress. In this section, we interpret these stylized facts using a version of the consumption habit model proposed by Campbell and Cochrane (1999), based on Verdelhan (2010). As we show, in this model, sorting currencies on their consumption growth over the last several quarters approximates sorting them on their risk aversion. Intuitively, a sequence of high consumption growth rates leads to high surplus consumption relative to habit and, therefore, to low risk aversion. Conversely, a country that experiences low consumption growth over several quarters will have a low surplus consumption ratio and, therefore, high levels of risk aversion.

It has previously been shown by Verdelhan (2010) that the habit model can reproduce the uncovered interest rate parity puzzle and that the resulting nonzero expected carry trade returns compensate investors for consumption growth risk. Unlike Verdelhan (2010), however, our version of the model explicitly allows for a global component in all countries' consumption growth rates. This is important for the interpretation of our results: while country-specific consumption growth shocks disappear at the portfolio level, the average country in any large portfolio will still be affected by global consumption growth risk. Thereby, marginal utility in high-growth, low-risk-aversion countries reacts less sensitively to consumption shocks than marginal utility in low-growth, high-risk-aversion countries. Therefore, the return spread between a portfolio of consumption boom countries and a portfolio of consumption bust countries — our $\text{HML}_{\Delta c}$ factor — reflects international differences in the exposure of marginal utility growth to global consumption growth risk. Hence, the habit formation model suggests that the $\text{HML}_{\Delta c}$ factor captures differences in risk aversion between countries.

We now proceed to present the model and then use simulated data to illustrate that the model can replicate some of the major empirical regularities that we discovered in the OECD data sample.

2.6.1 The model

Our setup closely follows Campbell and Cochrane (1999) and Verdelhan (2010). There are $k = 1 \ldots K$ endowment economies in each of which a representative agent is characterized by external habit preferences

$$E \sum_{t=0}^{\infty} \beta^t \frac{(C_t^k - H_t^k)^{1-\gamma} - 1}{1-\gamma}$$

where C_t^k denotes the level of country k's consumption of the single good, and H_t^k is the external consumption habit level. The relation between consumption and habits is captured by the surplus consumption ratio $\mathsf{S}_t^k \equiv (C_t^k - H_t^k)/C_t^k$, which depends on past consumption through the following process for the log surplus consumption ratio s_t:

$$\mathsf{s}_{t+1}^k = (1-\phi)\bar{\mathsf{s}} + \phi \mathsf{s}_t^k + \lambda(\mathsf{s}_t^k)(\Delta c_{t+1}^k - g)$$

where $0 < \phi < 1$ and where g and $\bar{\mathsf{s}}$ are the unconditional means of consumption growth and the log consumption surplus ratio.[10] The function $\lambda(\mathsf{s_t})$ governs how sensitively the surplus consumption ratio reacts to the current realization of consumption growth. It is given by

$$\lambda(\mathsf{s}_t) = \frac{1}{\bar{\mathsf{S}}}\sqrt{1 - 2(\mathsf{s}_t - \bar{\mathsf{s}})} - 1, \text{ when } \mathsf{s} \leq \mathsf{s}_{\max}, \text{ 0 elsewhere}$$

where $\bar{\mathsf{S}} = \sigma\sqrt{\frac{\gamma}{1-\phi-B/\gamma}}$, $\mathsf{s}_{\max} = \bar{\mathsf{s}} + (1 - \bar{\mathsf{S}}^2)/2$, and $B = \gamma(1-\phi) - (\gamma^2\sigma^2)/(\bar{\mathsf{S}}^2)$, and σ denotes the standard deviation of consumption growth.

In this model, the coefficient of relative risk aversion of country k is given by $-C_t^k U_{cc}(t)/U_c(t) =$

[10] We use sans serif letters (S and s) to denote the surplus consumption ratio and its logarithm, respectively. The spot nominal exchange rate and its logarithm continue to be denoted by the standard typeface S and s. Using different typefaces in this way allows us to stay in keeping with both the international finance literature and the literature on habit formation, which both use the letter 'S'.

γ/S_t^k. Hence, if country k's consumption is close to the habit level, the surplus consumption ratio of country k is low, which implies that the representative agent of country k is highly risk averse. In this model, the stochastic discount factor is given by

$$M_{t+1}^k = \beta \left(\frac{\mathsf{S}^k{}_{t+1} C_{t+1}^k}{\mathsf{S}_t^k C_t^k} \right)^{-\gamma} = \beta exp \left\{ -\gamma [g + (\phi - 1)(\mathsf{s}_t^k - \bar{\mathsf{s}}) + (1 + \lambda(\mathsf{s}_t^k))(\Delta c_{t+1}^k - g)] \right\}$$

where g is the mean growth rate of consumption. The risk-free interest rate is $r_t^k = \bar{r} - B(\mathsf{s}_t^k - \bar{\mathsf{s}})$ with $\bar{r} = -\ln(\beta) + \gamma g - (\gamma^2 \sigma^2)/(2\bar{\mathsf{S}}^2)$.[11] We follow Verdelhan (2010) and impose $B < 0$. This implies that risk-free interest rates are procyclical; that is, higher in countries with higher surplus consumption ratios.

We assume that consumption growth of country k follows an i.i.d. normal process.

$$\begin{aligned} \Delta c_{t+1}^k &= g + \xi_{t+1} + u_{t+1}^k \qquad \xi_{t+1} \sim \text{i.i.d. } N(0, \sigma_{glob}^2),\ u_{t+1}^k \sim \text{i.i.d. } N(0, \sigma_{idio}^2) \\ & \qquad\qquad\qquad\qquad \text{cov}(\xi_{t+1}, u_{t+1}^k) = 0 \end{aligned}$$

At each point in time, the average growth rate g and the global shock to consumption growth ξ_{t+1} are common to all countries, whereas u_{t+1}^k denotes country-specific shocks to consumption growth. Concerning the variance of the global and the country-specific shocks, we assume that $\sigma_{glob} = \sigma_{idio} = \sigma/\sqrt{2}$. As we will discuss shortly, the presence of a global component in consumption growth is important in explaining our results.

We assume that financial markets are complete, which implies that the change in the real exchange rate between two countries equals the ratio of the two countries' marginal utility growth rates or stochastic discount factors

$$\frac{Q_{t+1}^k}{Q_t^k} = \frac{M_{t+1}}{M_{t+1}^k}$$

where M_{t+1} is again the discount factor of the home country, Q_t^k is the real exchange rate measured in units of country k goods per one unit of the home country good, so that an increase in Q^k implies a depreciation of country k's currency vis-à-vis the home country. Taking logarithms and substituting in from above for the logarithmic pricing kernel, we obtain the rate of change of the real exchange rates

[11] For details about the derivation of equation (2.11), the reader is referred to Campbell and Cochrane (1999) and Verdelhan (2010).

$$\Delta q_{t+1}^k = \kappa_t + \gamma(1+\lambda(\mathsf{s}_t^k))(\Delta c_{t+1}^k - g) - \gamma(1+\lambda(\mathsf{s}_t))(\Delta c_{t+1} - g) \quad (2.11)$$

where κ_t summarizes all variables known at time t.[12]

It is instructive to compare this condition for optimal risk sharing with the one obtained from a model with constant relative risk aversion preferences without habit formation (see, e.g., Backus and Smith (1993) and Kollmann (1995)), which is given by the following.

$$\Delta q_{t+1}^k = \kappa_t + \gamma(\Delta c_{t+1}^k - \Delta c_{t+1})$$

The model without habit formation predicts that exchange rates move in lockstep with consumption growth differences between countries. It is well known that this condition is grossly violated in the data. By contrast, in the habit model, whether the real exchange rate appreciates or depreciates will not only depend on current differences in consumption growth between countries. Rather, past differences will matter as well, because they are reflected in differences in the surplus consumption ratio between the two countries. Specifically, if countries differ in their consumption histories, the real exchange rate will change even if both countries experience the same consumption shock $\Delta c_{t+1}^k = \Delta c_{t+1} \neq 0$: because the sensitivity function $\lambda(\mathsf{s})$ is low when surplus consumption is high, the country with the higher surplus and, therefore, the higher average consumption over the recent past will experience an appreciation if the common consumption shock is positive, or a depreciation if the shock is negative. The reason for this is that risk aversion in the high-surplus (low-λ) country is low and that marginal utility growth is less exposed to the common consumption shock. Optimal risk sharing entails that purchasing power is redistributed to the high-risk-aversion country in periods when both countries are hit by the same negative consumption growth shock.

Hence, in the habit model, countries differ in their exposure of marginal utility growth to the same common shock. These differences in exposure to common shocks are also the source of the currency risk premium in this model, which is given by the following.[13]

$$E(rx_{t+1}^k) = r_t^k - r_t - E_t(\Delta q_{t+1}^k) = \frac{\gamma^2\sigma^2}{\bar{\mathsf{S}}^2}(\mathsf{s}_t^k - \mathsf{s}_t) \quad (2.12)$$

Equation (2.12) shows that currencies of consumption boom countries generate positive

[12]When used without a superscript, the variables s_t and Δc pertain to the home country.

[13]for further details, see Campbell and Cochrane (1999) and Verdelhan (2010)

expected excess returns. This risk premium compensates for a likely depreciation of the currency in times of low aggregate consumption growth. As we show in our simulations, sorting currencies on past consumption growth is very similar to sorting them on their surplus consumption ratio.

To allow this intuition to extend to portfolios — as our empirical results suggest it does — consumption growth must therefore have a common (global) component that does not wash out in sufficiently large portfolios of currencies. To see this, average equation (2.11) over a subset of $I \subset \{1....K\}$ of our K currencies. If the number of elements in I, denoted here by $\#I$, is sufficiently large, we get the following.

$$\frac{1}{\#I}\sum_{k\in I}\Delta q_{t+1}^{k} \quad = \quad \tilde{\kappa}_t + \gamma\left(\frac{1}{\#I}\sum_{k\in I}(1+\lambda(\mathsf{s}_t^k))\right)\xi_{t+1} - \gamma(1+\lambda(\mathsf{s}_t))\Delta c_{t+1} \quad (2.13)$$

Specifically, forming portfolios by sorting currencies on their past consumption growth and assuming that there are many currencies in each of the consumption-growth-sorted portfolios, the stochastic component of the returns described by our consumption carry factor $HML_{\Delta c}$ is determined by changes in the average rate of change in the real exchange rate between high- and low-consumption-growth currencies, given by

$$\Delta q_{t+1}^{hl} \quad = \quad \hat{k}_t + \gamma[\lambda_t^h - \lambda_t^l]\xi_{t+1} \quad (2.14)$$

where λ_t^h and λ_t^l are the average values of the sensitivity function of high h and low l surplus consumption ratio country portfolios. Exchange rate changes between large portfolios of currencies are therefore solely driven by differences in the exposure to global consumption risk: portfolios of currencies from countries with high surplus consumption ratios — which recently have experienced a series of high consumption growth rates — appreciate if positive global consumption growth shocks occur, and depreciate if the global shock turns out to be negative. The reason is that marginal utility in countries with high surplus consumption (low risk aversion) has lower exposure to global consumption risk than countries with high risk aversion. Optimal risk sharing therefore entails that wealth is redistributed to high-risk-aversion countries when there are negative global shocks.

2.6.2 Calibration and results

We assume that all countries share the same set of parameters. The risk-aversion parameter γ is set equal to 2, which corresponds to the value chosen by Campbell and

Cochrane (1999) and Verdelhan (2010). We estimate the average consumption growth rate g and its standard error σ from the OECD data sample used in the main analysis of this study. Taking sample means over all 29 countries, we find that the quarterly consumption growth rate corresponds to $g = 0.65\%$, and its standard deviation is $\sigma = 0.4\%$. This implies a standard deviation of the global shock and the country-specific shock of $\sigma_{glob} = \sigma_{idio} = \sigma/\sqrt{2} = 0.28$. The country-specific endowment shocks u^k_{t+1}, which all have variance σ_{idio}, are uncorrelated across countries, but there is a common consumption growth shock in all countries' consumption growth rate ξ_{t+1} with variance σ_{glob}. The quarterly real risk-free interest rate is set equal to $\bar{r} = 0.74\%$, which corresponds to the average secondary market US T-bill rate measured over the period from the first quarter of 1990 to the fourth quarter of 2015. As in Verdelhan (2010), we set $B = -0.01$. The persistence parameter $\phi = 0.99$ is chosen such that the mean value of the consumption carry factor $\text{HML}_{\Delta c}$ approximately corresponds to its sample counterpart. These parameter values imply that $\beta = 0.95$, $\overline{\mathsf{S}} = 0.04$ and $\overline{\mathsf{S}}_{max} = 0.07$. All parameter values are thus close to the values chosen by Campbell and Cochrane (1999) and Verdelhan (2010), Table (2.9) presents an overview of the chosen parameter values.

With these parameters and 10 000 endowment shocks, we generate data and build currency portfolio returns, the dollar risk factor $\overline{rx}$ as well as the consumption carry factor $\text{HML}_{\Delta c}$. In analogy to the empirical analysis in this study, we generate data for 33 countries and then sort countries into six portfolios according to their consumption growth rates over the previous four quarters. Table (2.10) presents the moments for the currency portfolios that this simulation delivers.

Simulated portfolios of countries that have recently experienced higher consumption growth pay an investor who borrows in his home currency and invests in these portfolios higher returns on average. Furthermore, consumption boom countries have high surplus consumption ratios, which translate into low risk aversion, and thus relatively smooth intertemporal marginal rates of substitution in consumption. The more risk averse the investor is compared with the average country in a particular currency portfolio — that is, the lower his surplus consumption ratio is relative to the average portfolio surplus consumption ratio — the more exposed his marginal utility will be to consumption growth shocks. Currencies of countries with high exposure to global consumption growth shocks will therefore appreciate when a negative global consumption shock occurs. This reflects optimal risk sharing: the exchange rate appreciation redistributes purchasing power to the high-risk-aversion, high-marginal- utility country in recessions.

As carry trade returns are procyclical and thus risky, the investor demands a higher risk premium for investment into portfolios with higher surplus consumption ratios. Against the background of this model, we can therefore interpret our sorting of countries into portfolios according to their recent consumption growth rates as sorting countries on their surplus consumption ratios or risk aversion, and portfolios with higher past consumption growth rates expose the investor to more home and global consumption growth risk. This explains why consumption boom currencies pay higher expected returns.

Equation (2.14) suggests that within the framework of the consumption habit model outlined above, our consumption carry factor $\text{HML}_{\Delta c}$ should mirror global risk only, and it should be high if consumption growth is globally high and low otherwise. In the simulation with 33 countries and 10 000 global and country-specific endowment shocks, the correlation between the global consumption growth shock ξ_{t+1} and $\text{HML}_{\Delta c}$ equals about 0.4. This correlation is not perfect because with 29 countries, portfolios are not sufficiently large such that not all idiosyncratic endowment shocks u^k_{t+1} average out. Increasing the number of countries in the simulation increases this correlation, and for $K = 58$ countries, it equals about 0.7.

The simulated consumption carry factor $\text{HML}_{\Delta c}$ is a globally priced risk factor, whereas the mean currency return factor $\overline{rx}$ is not. Table (2.11) presents results from estimating the asset pricing model of Section (2.5) again, but instead of using the data from our sample of 29 OECD countries, test assets and pricing factors are constructed from simulated data. The habit model with the parameter values specified above generates the stylized facts that we described for the OECD data sample: country portfolio returns covary more strongly with the global recession factor $\text{HML}_{\Delta c}$ the higher their consumption growth rate has been recently, and the risk factor $\text{HML}_{\Delta c}$ is globally priced whereas the level factor $\overline{\text{rx}}$ is not.

2.7 Robustness checks

The Appendix presents several robustness checks that confirm our results. First, similar to Lustig et al. (2011) and Mancini et al. (2013) , we regress portfolio foreign exchange rate changes, $-\Delta s^j_{t+1}$, rather than portfolio carry trade returns, rx^j_{t+1}, on the dollar return factor and on $\text{HML}_{\Delta c}$. All $\text{HML}_{\Delta c}$ betas estimated using exchange rate changes as test assets presented in Table (A.3) are basically the same as those in Table (2.3) which were based on carry trade returns. Also, risk prices and factor loadings remain largely unchanged when exchange rate changes are used (see Table(A.4)). This implies that low past consumption growth currency portfolios offer insurance against $\text{HML}_{\Delta c}$ risk because they appreciate when the consumption carry factor $\text{HML}_{\Delta c}$ drops, not because the forward discounts on these currencies decline. On the other hand, high past consumption growth currency portfolios expose carry traders to $\text{HML}_{\Delta c}$ risk because they depreciate when $\text{HML}_{\Delta c}$ declines and not because forward discounts increase.

Second, we sort currencies into portfolios according to their β with respect to the consumption carry trade factor $\text{HML}_{\Delta c}$. To do so, we estimate the following regression for each currency k separately over rolling windows of 20 quarters.

$$rx_{t+1}^{k} = a^{k} + \beta_1^{k} \cdot \overline{\text{rx}}_{t+1} + \beta_2^{k} \cdot \text{HML}_{\Delta c,t+1} + \varepsilon_{t+1}^{k} \tag{2.15}$$

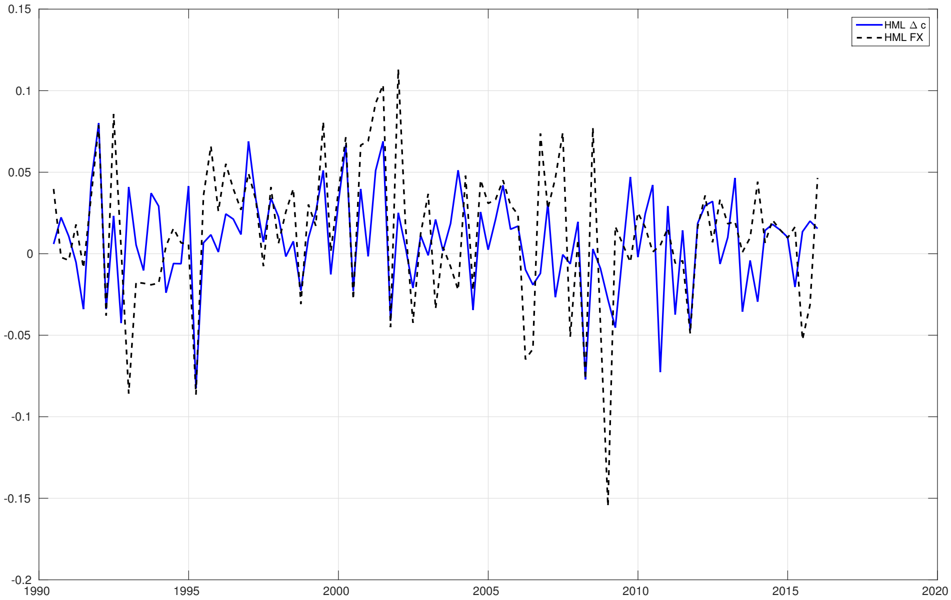
Hence, to obtain estimates $\beta_{2,t}^{k}$, we run regression (2.15) using time series that span the preceding 20 quarters; i.e. the quarters from $t-19$ to t. Because of this rolling window estimation procedure, the first five years of observations are lost, such that the analysis covers the period from 1995(1) to 2015(4). Table (A.5) reveals that portfolios of currencies with a high β_2^{k}, i.e. currencies that at a given point in time load heavily on the risk factor $\text{HML}_{\Delta c}$, pay higher returns on average and have experienced higher consumption growth rates over the preceding year. This confirms our result that high-consumption-growth currency portfolios are more exposed to global risk than low-consumption-growth portfolios. Third, in the same spirit as Mancini et al. (2013) , we add average portfolio forward discounts, $f_t^{j} - s_{t+1}^{j}$, as an explanatory variable when regressing portfolio average currency excess returns, rx_{t+1}^{j}, on the dollar risk factor and on the consumption carry factor. Table (A.6) reveals that all $\text{HML}_{\Delta c}$ betas remain nearly unchanged. Further, we estimate the model with alternative base currencies. Using the Swiss franc, the Canadian dollar, the British Pound, the Norwegian krone or the Australian dollar as base currencies, we obtain very similar results to those using the US dollar. By way of example, results for the Swiss franc are presented in Tables (A.7, A.8, A.9). Finally, we only use the most traded currencies of our sample to build and price consumption growth sorted portfolios; these currencies are the Australian dollar, Canadian dollar, Swiss franc, Euro (and before its inception the German mark, (and optionally also the Italian lira and the French franc)), British pound, Hong-Kong dollar, Japanese yen, Mexican peso, Norwegian krone, New Zealand dollar, Swedish krone, and the US dollar. We sort these currencies into 4 portfolios. Again, as shown in Tables (A.10, A.11) the time series betas for $\text{HML}_{\Delta c}$ increase monotonically from the low growth portfolio to the high growth portfolio, and $\text{HML}_{\Delta c}$ carries a significantly positive risk price, whereas the dollar risk factor, $\overline{\text{rx}}$, is not priced.

2.8 Summary and conclusion

In this paper, we have suggested a new, consumption-based factor for pricing currency returns. Our factor, which we refer to as the consumption carry factor or $\text{HML}_{\Delta c}$, is based on sorting currencies into portfolios based on past consumption growth and reflects the excess return of borrowing in countries with the lowest consumption growth in the world over the past year and investing in the currencies of countries that have experienced relative consumption booms over the last year. $\text{HML}_{\Delta c}$ is a global risk factor in the sense that it successfully explains the world cross-section of currencies — for portfolios sorted on either past consumption growth or on forward discounts as well as for individual currency pairs. In fact, we show that currencies with high past consumption growth trade at high forward discounts, so that countries with consumption booms appreciate much more than uncovered interest parity (UIP) would imply, whereas countries with low past consumption growth appreciate by less than is implied by UIP. These excess returns on consumption boom currencies are a compensation for the higher exposure of these currencies with respect to our global factor: high-consumption-growth currencies depreciate more during times of aggregate distress, exposing investors to global risk. The consumption carry factor $\text{HML}_{\Delta c}$ is as effective as other, purely financial factors that have been proposed in the recent literature. In fact, we show that sorting currencies into portfolios on past consumption growth is empirically equivalent to sorting on interest rates. This explains why — in spite of the high level of noise in consumption data as compared to interest rates — our factor $\text{HML}_{\Delta c}$ prices currencies almost as well as the HML_{FX} factor suggested by Lustig et al. (2011).

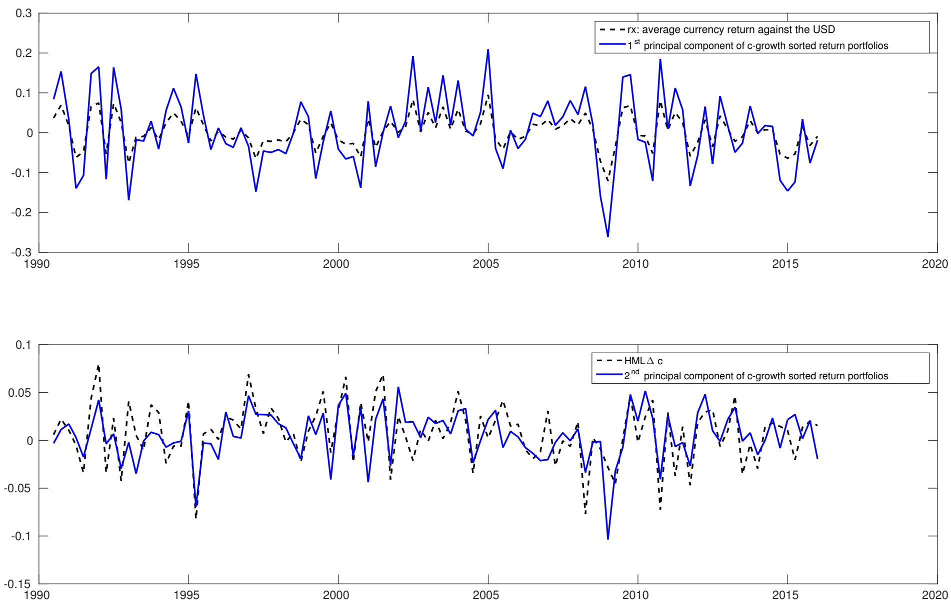
Our results are built on minimal theoretical restrictions and, in particular, are free of any specific assumptions about preferences. They therefore provide strong independent evidence that risk associated with longer- to medium-term movements in consumption are a key driver of the cross section of currency returns. While our results impose minimal restrictions on preferences, we showed that they can be interpreted in the context of a consumption-based habit formation model. In the habit model, sorting currencies on past consumption growth is akin to sorting countries according to their risk aversion (and equivalent to sorting on interest rates): consumption bust countries have low surplus consumption ratios and high risk aversion. Global consumption shocks therefore load more strongly on marginal utility in consumption bust countries, and optimal risk sharing requires that these currencies should appreciate in worldwide downturns — as we find in the data.

Figure 2.1: HML$_{FX}$ and HML$_{\Delta c}$



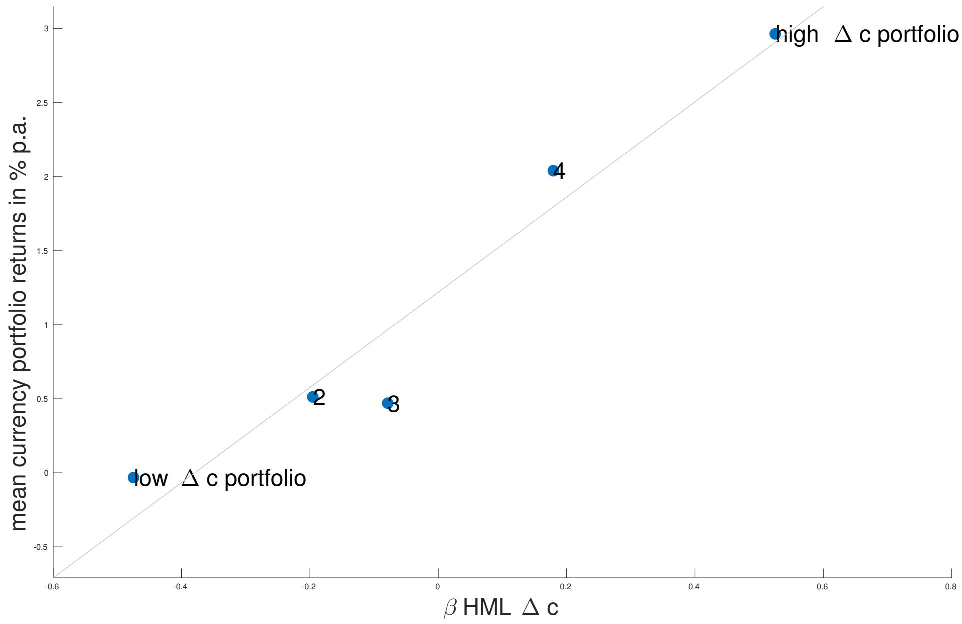
The blue solid line plots the consumption carry trade factor HML$_{\Delta c}$, and the black, dotted line shows the Lustig et al. (2011) carry trade factor HML$_{FX}$. The HML$_{\Delta c}$ factor is the cross-country average return a global investor obtains when she borrows in the currencies of countries which experienced low consumption growth over the last year and invests in currencies of countries with high past consumption growth. The HML$_{FX}$ factor corresponds to the return obtained from borrowing in low interest rate (forward discount) currencies and lending in high interest rate (forward discount) currencies. Both factors are constructed from quarterly data which encompass the OECD sample specified in the main text.

Figure 2.2: Principal components of USD returns of past consumption growth sorted currency portfolios and $\text{HML}_{\Delta c}$



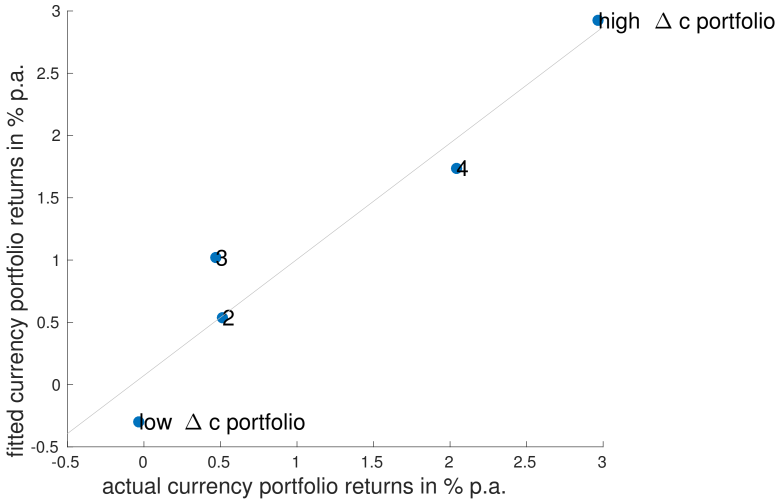
The upper figure plots the first principal component of quarterly USD returns obtained from investing in five past consumption growth sorted currency portfolios against $\overline{\text{rx}}$ which is the USD return from going long in equal weights in all currencies included in the sample at a given point in time. The lower panel plots the second principal component of the returns of the five consumption growth sorted portfolios against our consumption carry factor $\text{HML}_{\Delta c}$. Principal components are constructed using the covariance matrix of portfolio returns. The first principal component explains 82% of the variance present in portfolio returns, the second principal component explains 6.8%.

Figure 2.3: Time series estimates of $\beta^j_{\text{HML}_{\Delta c}}$ against average currency portfolio returns



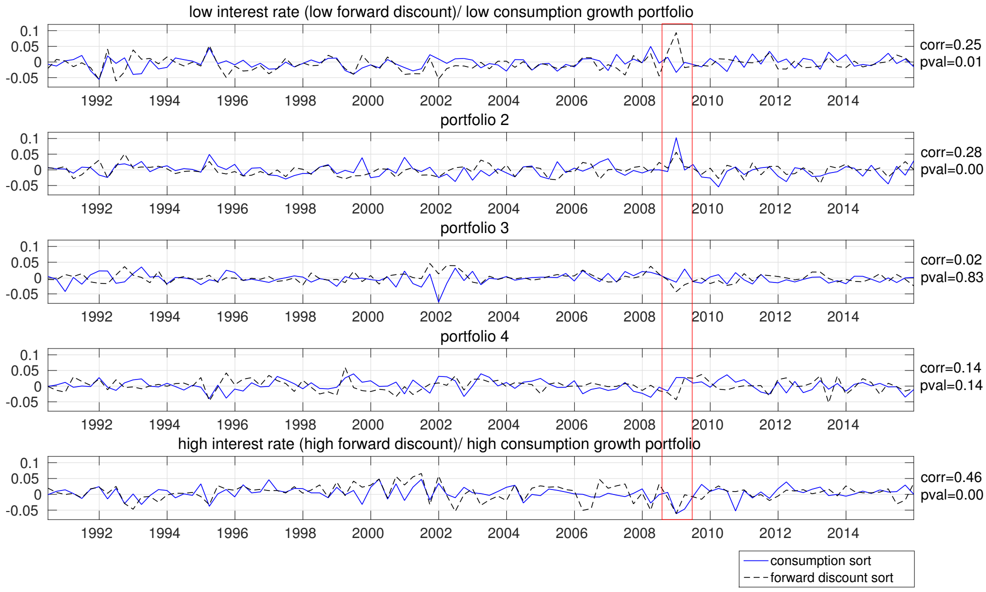
For each currency portfolio j, the figure plots the OLS estimate of $\beta^j_{\text{HML}_{\Delta c}}$ in the regression $rx^j_{t+1} = \alpha^j + \beta^j_{\overline{\text{rx}}} \cdot \overline{\text{rx}}_{t+1} + \beta^j_{\text{HML}_{\Delta c}} \cdot \text{HML}_{\Delta c, t+1} + \varepsilon^j_{t+1}$ on the horizontal axis against mean portfolio returns $(1/T) \sum_{t=1}^{T} rx^j_t$ on the vertical axis.

Figure 2.4: Actual vs fitted mean consumption growth sorted currency portfolio returns



The figure plots actual average consuption growth sorted currency portfolio returns against predicted average returns. The model to predict returns is given by $E(M_{t+1}rx^j_{t+1}) = 0$ and $M_t = 1 - b'(f_t - E(f))$. Factors f included in the analysis are $\overline{\text{rx}}$ and $\text{HML}_{\Delta c}$ as described in the text.

Figure 2.5: Difference between returns and $\overline{rx}$ of consumption growth sorted and forward discount sorted currency portfolios



The figures show time series of the deviation of currency portfolio returns from the average dollar return ($rx_t^j - \overline{\mathrm{rx}}_t$) for five portfolios sorted on past consumption growth (blue/solid line) and forward discounts (balck/dashed line) respectively. Currency portfolios are re-balanced each quarter. Returns plotted are quarterly returns. Table (A.1) in the appendix shows the currency composition of each portfolio at each point in time. Generally speaking, the returns of consumption growth sorted and forward discount sorted protfolios are very similar. However, the red rectangle marks the period of the global financial crisis, during which low interest rate currencies performed much better than low consumption growth currencies. Correlation coefficients and p-values quantify the time-series correlation of portfolio returns; small p-values indicate that a particular correlation is likely to be different from zero.

Table 2.1: Currency portfolios sorted on previous year consumption growth

portfolio j	low	2	3	4	high	$\overline{\text{rx}}$	$\text{HML}_{\Delta c}$
	excess return: rx^j						
mean	−0.0328	0.5121	0.4687	2.0416	2.9667	1.2445	2.9995
std	18.5312	17.8247	18.1688	16.6550	17.4474	16.0941	12.2156
Sharpe ratio	−0.0018	0.0287	0.0258	0.1226	0.1700	0.0773	0.2455
skewness	−0.1984	0.0686	−0.0197	0.2231	−0.7316	−0.1221	−0.4379
	spot change: Δs^j						
mean	−1.1478	−0.6573	−1.1337	0.0308	−0.0174		
std	18.5150	17.7673	18.0058	16.5034	17.4211		
	consumption growth: Δc^j						
mean	−0.3145	1.4313	2.3432	3.2124	5.0671		
std	2.4311	1.3452	1.2299	1.2155	1.7042		
	forward discount: $f^j - s^j$						
mean	0.0028	0.0029	−0.0012	0.0022	−0.0063		
std	0.0070	0.0050	0.0547	0.0273	0.1006		

This table presents descriptive statistics of USD returns of five currency portfolios. Portfolios are constructed by sorting currencies according to countries' consumption growth rate over the preceding year; portfolios are rebalanced quarterly. The first portfolio always contains currencies of countries with the lowest fifth of past consumption growth rates, and the last portfolio always contains currencies of countries with the highest fifth of past consumption growth rates. The second last column presents the average return obtained from borrowing in US dollars and investing in equal weights in all currencies of the sample, this return is labelled $\overline{\text{rx}}_{t+1}$. The last column shows descriptive statistics for the carry trade portfolio $\text{HML}_{\Delta c}$ which is given by a short position in all currencies of the low consumption growth portfolio and a long position in the currencies of the high consumption growth portfolio. Portfolio excess returns are calculated as $rx^j_{t+1} = f^j_t - s^j_t - \Delta s^j_{t+1}$, where rx^j_{t+1} is the average return from borrowing in US dollars and investing in equal weights in all currencies of portfolio j. f^j_t is the log 3M forward exchange rate of the currencies in portfolio j against the US dollar, and Δs^j_{t+1} is the log difference of the spot exchange rates between dates t and $t+1$; an increase in s^j corresponds to a depreciation of the currencies in portfolio j against the US dollar. Quarterly returns are calculated using average forward and spot exchange rates over the last ten trading days of each quarter. The statistics are presented in percentages per annum, except for the forward discounts. The sample encompasses data for 29 OECD countries and it spans the period from the first quarter of 1990 to the fourth quarter of 2015. Details on the composition of currency portfolios are given in Table (A.1) in the appendix.

Table 2.2: Descriptive statistics of candidate pricing factors

	$\text{HML}_{\Delta c}$	HML_{FX}	$\overline{\text{rx}}$	VOL	MSCI	mean(Δc)	var(Δc)
mean	2.9995	5.0657	1.2445	0.0001	2.2819	2.5795	7.4251
standard deviation	12.2156	17.2944	16.0941	0.0012	17.5448	1.5199	5.0880
sharpe ratio	0.2455	0.2929	0.0773	–	0.1301	–	–
skewness	−0.4379	−0.6053	−0.1221	–	−0.8467	−1.7346	–

correlation matrix of pricing factors

	$\text{HML}_{\Delta c}$	HML_{FX}	$\overline{\text{rx}}$	VOL	MSCI	mean(Δc)	var(Δc)
$\text{HML}_{\Delta c}$	1	0.4841	−0.1167	−0.2373	0.1937	0.0821	0.0092
		(0.0000)	(0.2403)	(0.0158)	(0.0499)	(0.4098)	(0.9265)
HML_{FX}		1	0.1156	−0.4900	0.3308	0.1705	0.0044
			(0.2450)	(0.0000)	(0.0006)	(0.0850)	(0.9648)
$\overline{\text{rx}}$			1	−0.3507	0.3485	0.0099	0.0549
				(0.0003)	(0.0003)	(0.9206)	(0.5817)
VOL				1	−0.5184	0.1984	−0.1716
					(0.0000)	(0.0446)	(0.0830)
MSCI					1	−0.0556	0.0579
						(0.5769)	(0.5610)
mean(Δc)						1	−0.3927
							(0.0000)
var(Δc)							1

This table presents descriptive statistics as well as the cross-correlation matrix of different pricing factors used in asset pricing models. The factors $\text{HML}_{\Delta c}$ and HML_{FX} are the difference in the returns of high and low consumption growth and forward discount sorted currency portfolios. The foreign exchange volatiliy innovation factor VOL is constructed as described in Menkhoff et al. (2012a). The factors mean(Δc) and var(Δc) are the cross-sectional mean and variance of annual consumption growth rates. MSCI corresponds to the growth rate (log difference) of the MSCI world index, of which end of quarter values have been downloaded from http://www.msci.com/products/indices/performance.html. All moments are reported in percentages per annum, only for the volatiliy factor VOL, the mean and the standard deviation are quarterly values. In the lower panel, the numbers reported in parentheses are p-values for the null that the correlation between two risk factors is zero. If the p-value is small, say less than 0.05, then a particular correlation is significantly different from zero.

Table 2.3: Factor betas

	a^j	$\beta^j_{\overline{\text{rx}}}$	$\beta^j_{\text{HML}_{\Delta c}}$	$\overline{R}^2$
low	0.0003	1.0151	−0.4746	
	(0.2295)	(22.4508)	(−10.1541)	0.94
2	−0.0002	0.9608	−0.1952	
	(−0.1094)	(11.2704)	(−2.8803)	0.79
3	−0.0015	1.0516	−0.0790	
	(−1.0759)	(28.5594)	(−1.3500)	0.88
4	0.0008	0.9572	0.1789	
	(0.3871)	(22.3283)	(4.2258)	0.84
high	0.0003	1.0151	0.5254	
	(0.2295)	(22.4508)	(11.2429)	0.93

This table shows estimates and t-statistics obtained from running the following time series regression for each currency portfolio j separately:

$$rx^j_{t+1} \quad = \quad a^j + \beta^j_{\overline{\text{rx}}} \cdot \overline{\text{rx}}_{t+1} + \beta^j_{\text{HML}_{\Delta c}} \cdot \text{HML}_{\Delta c,t+1} + \varepsilon^j_{t+1}$$

Standard errors are corrected for serial correlation using the Newey and West (1987) estimator for the covariance matrix of the error terms ε^j_{t+1}.

Table 2.4: Risk price and factor loadings

	$\lambda_{\overline{\text{rx}}}$	$\lambda_{\text{HML}_{\Delta c}}$	$b_{\overline{\text{rx}}}$	$b_{\text{HML}_{\Delta c}}$
OLS estimate	0.0030	0.0081	2.7004	9.1339
t-stat	(0.7238)	(2.4641)	(0.8870)	(2.1513)
pricing error test		0.71		0.70
R^2		0.93		0.93
GLS estimate	0.0031	0.0078	2.0396	8.1186
t-stat	(0.7261)	(2.4992)	(0.7223)	(2.3936)
pricing error test		0.77		0.79

This first two columns of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad \beta^j_{\overline{\text{rx}}} \cdot \lambda_{\overline{\text{rx}}} + \beta^j_{\text{HML}_{\Delta c}} \cdot \lambda_{\text{HML}_{\Delta c}} + \alpha^j$$

$\beta^j_{\overline{\text{rx}}}$ and $\beta^j_{\text{HML}_{\Delta c}}$ correspond to the estimates obtained from running time series regressions of portfolio returns on the risk factors as reported in Table (2.3). Here, the factor βs and the prices of risk $\lambda_{\overline{\text{rx}}}$ and $\lambda_{\text{HML}_{\Delta c}}$ are estimated jointly using GMM. This approach yields standard errors which correct for the fact that the βs are estimates. The third and the fourth column of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad cov(\overline{\text{rx}}, rx^j) \cdot b_{\overline{\text{rx}}} + cov(\text{HML}_{\Delta c}, rx^j) \cdot b_{\text{HML}_{\Delta c}} + \alpha^j$$

where again, covariances and factor loadings b have been estimated jointly using GMM. Let $\mu^j = \frac{1}{T}\sum_{t=1}^{T} rx^j_t$ denote the (time-) average return on portfolio j and $\mu = \begin{bmatrix} \mu^1, & \mu^2, & \ldots & \mu^J \end{bmatrix}'$ the $J \times 1$ vector stacking these average returns. Furthermore, let $\overline{\mu} = \frac{1}{J}\sum_{j=1}^{J} \mu^j = \mu' 1/J$ where 1 is a $J \times 1$ vector of ones. Then R^2 measures are obtained using $R^2 = 1 - \frac{\hat{\alpha}'\hat{\alpha}}{(\mu - \overline{\mu}1)'(\mu - \overline{\mu}1)}$ where $\hat{\alpha} = \begin{bmatrix} \alpha^1, & \alpha^2, & \ldots & \alpha^J \end{bmatrix}'$ is the vector of average portfolio j pricing errors α^j given by $\alpha^j = \overline{rx}^j - cov(\hat{f}, rx^j)'\hat{b} = \overline{rx}^j - \widehat{\beta}^{j\prime}\widehat{\lambda}$ where $\beta^j = \begin{bmatrix} \beta^j_{\overline{\text{rx}}}, & \beta^j_{\text{HML}_{\Delta c}} \end{bmatrix}'$ and $\lambda^j = \begin{bmatrix} \lambda^j_{\overline{\text{rx}}}, & \lambda^j_{\text{HML}_{\Delta c}} \end{bmatrix}'$. Hats denote estimates. The pricing error test reports the p-value for the null that the pricing errors are jointly zero. If the p-value is small, say less than 0.05, then pricing errors are significantly different from zero.

Table 2.5: Forward discount sorted currency portfolios and alternative risk factors

	Factor Prices λ					
	$\overline{\text{rx}}$	$\text{HML}_{\Delta c}$	HML_{FX}	VOL	p-value	R^2
Estimate	0.0032	0.0156				
t-stat	(0.7706)	(2.3521)			0.7186	0.95
Estimate	0.0033		0.0124			
t-stat	(0.7769)		(2.5654)		0.8742	0.97
Estimate	0.0033			−0.0006		
t-stat	(0.7835)			(−2.4059)	0.3027	0.88

This table reports the results obtained from estimating the following asset pricing model using three different sets of pricing factors

$$E(rx^j) \quad = \quad \beta^{j\prime}\lambda$$

Pricing factors are the mean dollar currency return $\overline{rx}$ plus either the consumption-based carry trade factor $\text{HML}_{\Delta c}$, or the forward-discount based carry trade factor HML_{FX}, which has been suggested by Lustig et al. (2011), or the FX volatiliy innovation factor VOL, which has been proposed by Menkhoff et al. (2012a). VOL is the innovation to global FX volatiliy and is constructed as described in their paper (p. 692). As in Lustig et al. (2011) and Menkhoff et al. (2012a), test assets are six forward discount sorted currency portfolios. The data encompasses the OECD sample specified in the main text, and it spans the period from 1990(1) to 2015(4). For each model, the pricing error test reports the p-value for the null that the pricing errors are jointly zero; if the p-value is small, say less than 0.05, then pricing errors are significantly different from zero. The R^2 measure is obtained as described in the notes of table (2.4).

Table 2.6: Factor betas for forward discount sorted portfolio returns as test assets

	a^j	$\beta^j_{\overline{\text{rx}}}$	$\beta^j_{\text{HML}_{\Delta c}}$	a^j	$\beta^j_{\overline{\text{rx}}}$	$\beta^j_{\text{HML}_{FX}}$	a^j	$\beta^j_{\overline{\text{rx}}}$	β^j_{VOL}
low	−0.0037	0.8261	−0.3627	−0.0008	0.9161	−0.4661	−0.0083	0.9641	10.1782
	(−2.1880)	(10.6243)	(−5.0687)	(−0.7099)	(25.5596)	(−14.8913)	(−3.8052)	(11.9054)	(4.0823)
2	−0.0002	1.0579	−0.1270	0.0008	1.0889	−0.1593	−0.0021	1.1243	5.3040
	(−0.1030)	(14.1074)	(−1.7172)	(0.5116)	(17.8303)	(−3.6423)	(−1.2416)	(22.0614)	(3.6572)
3	0.0007	1.0578	−0.0514	0.0006	1.0651	−0.0217	0.0002	1.0727	0.9988
	(0.3671)	(22.2738)	(−0.9347)	(0.2945)	(23.0108)	(−0.5669)	(0.0947)	(23.9377)	(0.6432)
4	0.0003	1.0799	0.1641	0.0007	1.0557	0.0783	0.0028	0.9942	−6.8409
	(0.2026)	(16.2726)	(2.0524)	(0.3868)	(15.3447)	(1.3348)	(1.5481)	(15.3385)	(−4.2729)
high	0.0031	1.0136	0.3514	−0.0008	0.9161	0.5339	0.0072	0.8952	−8.3859
	(1.2819)	(16.0482)	(3.6676)	(−0.7099)	(25.5596)	(17.0540)	(2.5220)	(12.0744)	(−4.0656)

The table shows time series beta estimates and t-statistics obatined from regressing forward-discount sorted portfolio returns on different risk factors. Standard errors are corrected for serial correlation using the Newey and West (1987) estimator for the covariance matrix of the error terms.

Table 2.7: Horse race

	risk price λ					factor loadings b					
	$\overline{\text{rx}}$	$\text{HML}_{\Delta c}$	HML_{FX}	VOL	p-value	$\overline{\text{rx}}$	$\text{HML}_{\Delta c}$	HML_{FX}	VOL	p-value	R^2
Estimate	0.0032	0.0107				3.0399	12.0027				
t-stat	(0.7559)	(2.6230)			0.4349	(0.9258)	(2.2634)			0.4047	0.86
Estimate	0.0032		0.0136			1.0677		7.2458			
t-stat	(0.7526)		(2.7043)		0.8113	(0.3416)		(1.9583)		0.7786	0.91
Estimate	0.0032			−0.0006		−2.7560			−454.5		
t-stat	(0.7537)			(−2.2393)	0.4212	(−0.6737)			(−1.3442)	0.4322	0.80
Estimate	0.0032	0.0078	0.0123			1.9140	5.6354	4.5191			
t-stat	(0.7557)	(2.3642)	(2.4225)		0.9508	(0.5981)	(1.2444)	(1.2404)		0.9373	0.97
Estimate	0.0032		0.0135	−0.0002		0.6307		6.5522	−50.3977		
t-stat	(0.7527)		(2.7568)	(−0.9198)	0.7609	(0.1836)		(1.5862)	(−0.1865)	0.7218	0.91
Estimate	0.0032	0.0088		−0.0004		0.5315	7.6727		−204.5		
t-stat	(0.7568)	(2.7591)		(−1.5478)	0.5339	(0.1528)	(1.9467		(−0.8124)	0.4759	0.91
Estimate	0.0032	0.0079	0.0124	−0.0001		2.4613	5.9573	5.1554	57.5486		
t-stat	(0.7552)	(2.5642)	(2.4574)	(−0.5648)	0.9316	(0.7441)	(1.4166)	(1.1869)	(0.2529)	0.9155	0.97

The panel on the left reports OLS cross-sectional regression estimation results for the following model: $E(rx^j) = \beta^{j\prime}\lambda$, and the panel on the right reports OLS cross-sectional regression estimation results for the following model: $E(rx^j) = cov(f, rx^j)'b$. Factor βs and the risk prices λ, as well as factor loadings b and the covariances between factors f and test asset returns rx are estimated jointly using GMM (for details see Cochrane (2005), chapter 13). There are 10 test assets, five consumption growth sorted currency portfolios plus five forward discount sorted currency portfolios. Pricing factors are the mean dollar currency return $\overline{\text{rx}}$, our consumption carry trade factor $\text{HML}_{\Delta c}$, the Lustig et al. (2011) forward discount carry trade factor HML_{FX}, and the Menkhoff et al. (2012a) currency market volatility innovation factor VOL (see p. 692 of their paper). Pricing factors and test asset returns are constructed from the OECD data set used in this paper, only the VOL factor is build from a larger data set. Quarterly returns are obtained from average spot- and forward exchange rates over the last ten trading days of each quarter; the data spans the period from 1990(1) to 2015(4). For each model, the pricing error test reports the p-value for the null that the pricing errors are jointly zero. The adjusted R^2 are obtained as described in the notes of Table (2.4).

Table 2.8: Pricing the cross-section of individual currencies: panel estimation

	γ_1	γ_2	γ_3	γ_4	α^k	R^2
	$rx_{t+1}^k = \alpha^k + \gamma_1 \cdot \left(\widetilde{c}_t^k \cdot \text{HML}_{\Delta c,t+1}\right) + \gamma_2 \cdot \widetilde{c}_t^k + \gamma_3 \cdot \text{HML}_{\Delta c,t+1} + \gamma_4 \cdot \overline{\text{rx}}_{t+1} + \varepsilon_{t+1}$					
estimate	0.1104	0.0001	0.0199	0.9776		
t-stat	(7.3359)	(0.3520)	(0.4942)	(27.0108)	p-value for α^k jointly zero: 0.50	0.58
	$rx_{t+1}^k = \alpha^k + \gamma_1 \cdot \left(\widetilde{c}_t^k \cdot \text{HML}_{\Delta c,t+1}\right) + \gamma_2 \cdot \widetilde{c}_t^k + \tau_{t+1} + \varepsilon_{t+1}$					
estimate	0.1471	0.0001				
t-stat	(7.9257)	(0.2759)			p-value for α^k jointly zero: 0.36	0.56
	$-\Delta s_{t+1}^k = \alpha^k + \gamma_1 \cdot \left(\widetilde{c}_t^k \cdot \text{HML}_{\Delta c,t+1}\right) + \gamma_2 \cdot \widetilde{c}_t^k + \gamma_3 \cdot \text{HML}_{\Delta c,t+1} + \gamma_4 \cdot \overline{\text{rx}}_{t+1} + \varepsilon_{t+1}$					
estimate	0.1069	0.0003	0.0211	0.9691		
t-stat	6.9591	0.7759	0.5346	26.7442		0.58
	$-\Delta s_{t+1}^k = \alpha^k + \gamma_1 \cdot \left(\widetilde{c}_t^k \cdot \text{HML}_{\Delta c,t+1}\right) + \gamma_2 \cdot \widetilde{c}_t^k + \tau_{t+1} + \varepsilon_{t+1}$					
estimate	0.1426	0.0001				
t-stat	(7.8686)	(0.2522)				0.57

This table shows panel estimation results with single countries' currency return as the dependent variables and our consumption based carry trade factor $\text{HML}_{\Delta c}$ as the expanatory factor. $rx_{t+1}^k = i_t^k - i_t^{US} - \Delta s_{t+1}^k$ is the return an investor obtains by borrowing in US dollars and investing into the currency of country k over the quarter form t to $t+1$. $\widetilde{c}_t^k = \Delta c_t^k - \Delta c_t^{US}$ is the difference between the US consumption growth rate and the consumption growth rate of country k over the quarters from $t-4$ to t. α^k are country-specific intercepts (country-fixed-effects), and τ_t is a time fixed effect. Δs_{t+1}^k is the quarterly change (log difference) of the bilateral exchange rate between the currency of country k and the US dollar. An increase in s^k indicates a depreciation of the currency of country k towards the US dollar. The data spans the period 1990(1) - 2015(4), and countries are included in the panel whenever data is available — see the data section in the appendix. Standard errors are autocorrelation and heteroscedasticity consistent following (Newey and West (1987)).

Table 2.9: Habit model, parameter values

	this paper	Campbell and Cochrane (1999)	Verdelhan (2010)
	calibrated parameters		
$g(\%)$	0.65	0.74	0.53
$\sigma(\%)$	0.38	0.75	0.51
$\sigma_{idio}(\%)$	0.27	-	-
$\sigma_{glob}(\%)$	0.27	-	-
$\bar{r}(\%)$	0.74	0.23	0.34
γ	2.00	2.00	2.00
ϕ	0.99	0.97	0.99
B	-0.01	-	-0.01
ρ		-	0.15
	implied parameters		
β	0.995	0.97	1.00
$\bar{S}$	0.04	0.06	0.07
S_{max}	0.07	0.09	0.12

This table presents the parameters of the habit formation model outlined in section (6) and their chosen values in this paper, in Campbell and Cochrane (1999) and in Verdelhan (2010). The data is at quarterly frequency. For this paper, the reference period is 1990(1)-2015(4) (1947-1995 in Campbell and Cochrane (1999), and 1947(2)-2004(4) in Verdelhan (2010)). The average consumption growth rate g and its standard error σ are estimated from the OECD data sample used in the main analysis of this study. The standard error of consumption growth σ is decomposed into a global and an idiosyncratic component such that $\sigma_{glob} = \sigma_{idio} = \sigma/\sqrt{2}$, whereby we assume that country-specific and global consumption growth shocks are uncorrelated. The quarterly risk-free rate corresponds to the US average 3-Month Treasury Bill secondary market rate (source: FRED database), it amounts to 0.74 percent. The persistence parameter ϕ is chosen such that the mean value of the consumption carry factor $HML_{\Delta c}$ approximately corresponds to its sample counterpart. In Verdelhan (2010), ρ corresponds to the correlation of each simulated countries consumption growth shocks.

Table 2.10: Habit model, simulation results: currency portfolios

portfolio j	low	2	3	4	high	$\overline{\text{rx}}$	HML$_{\Delta c}$
	excess return: rx^j						
mean	−1.3256	−0.3523	0.3158	0.8791	1.4014	0.1954	2.7270
std	64.3859	64.4582	63.7416	63.1764	63.3794	59.8827	35.9967
Sharpe ratio	−0.0206	−0.0055	0.0050	0.0139	0.0221	0.0033	0.0758
	spot change: Δq^j						
mean	1.0069	0.4118	−0.0187	−0.3942	−0.59251		
std	64.2002	64.2697	63.5460	63.0002	63.2079		
	consumption growth: $\Delta c^j_{t-4,t}$						
mean	1.8418	2.2714	2.5245	2.7992	3.2555		
std	0.5556	0.5516	0.5494	0.5491	0.5557		
	surplus consumption ratio: s_t						
mean	0.0423	0.0453	0.0473	0.0490	0.0521		
std	0.0150	0.0151	0.0149	0.0146	0.0142		
	interest rate differential: $r^j - r$						
mean	−2.3052	−0.2450	0.6118	1.2928	1.9790		
std	2.3521	1.8582	1.8280	1.9202	2.1617		

This table presents descriptive statistics for five currency portfolios obtained from simulated data. With the parameters presented in Table (2.9) and $10'000$ endowment shocks, we use the habit model outlined in section (2.6) to generate data for 29 hypothetical countries which then are sorted into portfolios according to their consumption growth rate over the previous four periods. This procedure is analogous to the approach taken in the empirical asset pricing analysis of this paper. The first portfolio always contains countries with the lowest fifth of consumption growth rates, and the last portfolio always contains countries with the highest fifth of consumption growth rates. Currency excess returns rx^j_{t+1}, which an investor obtains when borrowing at home and investing into particular currency portfolios, average interest rate differentials between portfolio j and the home country $r^j_{t+1} - r_{t+1}$, consumption growth rates Δc^j_t and exchange rate changes Δq^j_{t+1} are expressed in percentage per annum. The exchange rate is measured in units of foreign goods per home good, such that $\Delta q^j < 0$ implies an appreciation of the foreign good. The portfolio average surplus consumption ratios s_t refer to quarterly values. The second last column presents descriptive statistics for the simulated return the home investor gains when borrowing at home and investing each period in all the other countries of the sample, and the last column presents the returns the average (global) investor obtains when borrowing in low growth countries and investing in high growth countries: as in the main analysis of this paper, HML$_{\Delta c}$ is given by the difference in returns of the high and the low growth portfolio.

Table 2.11: Habit model, asset pricing results using simulated data

Panel A: risk prices and factor loadings				
	$\lambda_{\overline{\text{rx}}}$	$\lambda_{\text{HML}_{\Delta c}}$	$b_{\overline{\text{rx}}}$	$b_{\text{HML}_{\Delta c}}$
OLS estimate	0.0005	0.0070	0.0204	0.8615
t-stat	(0.2894)	(7.4505)	(0.2966)	(7.4237)
pricing error test		0.03		0.026
R^2		0.87		0.87

Panel B: time series regression				
	a^j	$\beta^j_{\overline{\text{rx}}}$	$\beta^j_{\text{HML}_{\Delta c}}$	R^2
low	−0.0001	1.0027	−0.5488	
	(−0.2167)	(371.3243)	(−113.1387)	0.96
2	−0.0014	0.9994	0.0085	
	(−2.3564)	(182.3644)	(0.9103)	0.86
3	0.0001	0.9934	0.0288	
	(0.1661)	(201.4177)	(3.2815)	0.87
4	0.0012	1.0007	0.0665	
	(2.4701)	(211.5931)	(8.6029)	0.90
high	−0.0001	1.0027	0.4512	
	(−0.2167)	(371.3243)	(93.0060)	0.96

This table shows estimates and standard errors obtained from running the same asset pricing exercise as in the empirical analysis of this paper, but instead of the OECD data set, simulated data are used. From the habit model outlined in section (2.6) and 10000 endowment shocks, data for 29 hypothetical countries are constructed, and at each point in time, countriesare sorted into five portfolios according to their consumption growth rates realized over the preceding four periods. Test asset returns are the returns a home investor obtains each period by borrowing at home and investing in the different portfolios.
In **panel A**, the first two columns report results from estimating the following cross-sectional regression using GMM:

$$E(rx^j) \quad = \quad \beta^j_{\overline{\text{rx}}} \cdot \lambda_{\overline{\text{rx}}} + \beta^j_{\text{HML}_{\Delta c}} \cdot \lambda_{\text{HML}_{\Delta c}} + \alpha^j$$

The third and the fourth columns show results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad cov(\overline{\text{rx}}, rx^j) \cdot b_{\overline{\text{rx}}} + cov(\text{HML}_{\Delta c}, rx^j) \cdot b_{\text{HML}_{\Delta c}} + \alpha^j$$

where covariances and factor loadings b have been estimated jointly using GMM. R^2 measures are obtained as described in the notes below Table (2.4). The pricing error test reports the p-value for the null that the pricing errors jointly are zero. If the p-value is small, say less than 0.05, then pricing errors are significantly different from zero.
Panel B shows estimates and t-statistics obtained from running the following time series regression for each currency portfolio j separately:

$$rx^j_{t+1} \quad = \quad a^j + \beta^j_{\overline{\text{rx}}} \cdot \overline{\text{rx}}_{t+1} + \beta^j_{\text{HML}_{\Delta c}} \cdot \text{HML}_{\Delta c,t+1} + \varepsilon^j_{t+1}$$

Chapter 3

The Swiss franc's honeymoon

The Swiss franc's honeymoon

Alexandra Janssen   Rahel Studer-Suter

Abstract

Starting from the stylized fact that the Swiss franc is a safe haven currency, this paper focuses on the determinants of the Swiss franc during the lower bound regime from September 2011 to January 2015. We describe the Swiss franc as a function of global market risk fundamentals and find that the macroeconomic model outlined by Krugman (1991) describes the EUR/CHF exchange rate well during this time. We show that, as predicted by Krugman's model, the sole expectation that the Swiss National Bank would prevent the Swiss franc from appreciating beyond 1.20 to the euro muted the sensitivity of EUR/CHF to global market risk. An important assumption for the model prediction to hold is that the central bank's commitment to the exchange rate target is credible. We thus use EUR/CHF option prices together with the global market risk fundamental to assess the credibility of the lower bound. We find that the only true credibility issue was in November 2014. After November 2014, the Swiss National Bank could convince markets anew from its target-zone policy and suspend the lower bound unexpectedly a few weeks later.

JEL Classification Numbers: E52, E58, F31, G01

Keywords: exchange rate target zone, safe haven currency, volatility smile

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3.1 Introduction

The Swiss franc is a safe haven currency: during the last hundred years, the Swiss franc has been appreciating whenever markets have been volatile and declining worldwide (see for example Baltensperger and Kugler, 2016). Likewise, the franc rapidly gained in value against all major currencies in the aftermath of the Global Financial Crisis of 2008/2009. In the wake of the subsequent European sovereign debt crisis, low interest rates and a massive expansion of the Swiss monetary base could not halt the unchecked appreciation of the Swiss franc against all major currencies. As the strength of the Swiss franc started to severely challenge the Swiss economy, on 6 September 2011, the Swiss National Bank (SNB) took action and declared to enforce a minimum exchange rate of 1.20 Swiss francs per one euro for an indefinite period. Markets were surprised by this sudden policy change, but probably even more so when the SNB abruptly declared the end of this lower bound regime on 15 January 2015.

Taking the safe haven property of the Swiss franc as a given, this paper follows a macroeconomic approach and describes the Swiss franc as a function of fundamentals that mirror global market sentiment, such as for example the VIX.[1] In particular, this paper focuses on the determinants of the Swiss franc during the lower bound regime over September 2011 to January 2015. We find that the Krugman (1991) model for the behavior of exchange rates within target zones describes the Swiss franc/euro exchange rate well during this particular time. In Krugman's model, the market's expectation that a central bank will intervene once its exchange rate is about to surpass the announced bounds is sufficient to stabilize exchange rates everywhere. Accordingly, we find that no actual Swiss National Bank interventions were needed to shield the Swiss franc from worldwide market turbulences, with two exceptions, one during spring 2012, and a second one during fall 2014. As Krugman's (1991) model predicts, the sensitivity of the Swiss franc to its global risk fundamentals — the Swiss franc's safe haven property — declined as the franc approached the EUR/CHF = 1.20 lower bound. Further, we contrast this result to the behavior of the Swiss franc during periods characterized by either a freely floating exchange rate, or by substantial Swiss National Bank interventions independent of an explicitly communicated exchange rate target.

In this paper, we show that Krugman's (1991) simple, though elegant model can illustrate how powerful the SNB's monetary policy experiment has been. This result is remarkable since many empirical research on exchange rate target zones have rather

[1]Throughout this paper, VIX denotes the CBOE Volatility Index which is derived from the traded option contracts on the S&P500 index.

rejected version of Krugman's (1991) approach. The most crucial model assumption is that the central bank's commitment to the exchange rate target is *credible*. Applied to the Swiss-franc-lower-bound-regime, the model requires that *markets put no probability on exchange rate realizations below* EUR/CHF = 1.20. The second part of this paper qualifies our results through the lens of this strong prerequisite. We crystallize a Swiss-franc specific *mistrust-factor* from EUR/CHF currency option prices and from global option prices – from the VIX in particular – and conclude that the Swiss National Bank's credibility with respect to the lower bound regime has severely been put into question only over November 2014. We think that the strong appreciation pressure on the Swiss franc over spring 2012 was rather related to fear of a break-up of the Eurozone which, obviously, would have ended the Swiss franc lower bound regime, than to mistrust in the SNB's lower-bound commitment. We assert that the SNB suspended the "Swiss franc's lower-bound honeymoon" a few weeks after true mistrust towards the SNB's exchange rate policy announcement had arisen for the first time.

The next section introduces the global market risk state variable VIX as a macroeconomic fundamental for EUR/CHF. It unveils that the explanatory power of this VIX-global-market-risk-fundamental for the Swiss franc varies over episodes characterized by different Swiss National Bank monetary policy regimes. Section (3.3) presents the Krugman (1991) exchange-rate-target-zone model and shows that it describes the behavior of EUR/CHF well during the Swiss franc lower bound episode. Krugman's (1991) macroeconomic model describes exchange rates as a function of macroeconomic fundamentals, K. Whenever we refer to the VIX in its role as such an exchange rate fundamental, K, we refer to it as K_{VIX}. Section (3.4) uses currency option prices to assess the credibility of the SNB's lower-bound commitment. This is not only a crucial condition in the Krugman model, but also interesting per se. Section (3.5) relates the analysis in this paper to the recent literature, and Section (4.8) concludes.

3.2 Episodes of different Swiss franc regimes

To begin with, Figure (4.1) plots the Swiss franc/euro spot exchange rate together with the VIX, and with the Swiss National Bank's foreign currency reserves, over 2008 to 2016. Vertical lines separate five episodes of different Swiss franc exchange rate policy regimes. These episodes are identified by the SNB's officially announced policy stance in the Quarterly Bulletins,[2] together with the evolution of the central bank's foreign

[2] https://www.snb.ch/en/iabout/pub/oecpub/id/pub_oecpub_quartbul

currency reserves.[3] Interestingly, these episodes also differ by the volatility of EUR/CHF conditional on the VIX- volatility of global markets. This observation forms the starting point of our analysis.

First, we identify two "free-float-periods" the first of which stops in April 2009, and the second reaches from June 2010 to September 2011. Over these episodes, the SNB had not communicated any exchange rate target and its foreign currency reserves remained broadly unchanged. When floating freely, the Swiss franc is volatile and co-moves strongly with the VIX: global market sentiment, as indicated by this index, importantly determines the value of the Swiss franc. This stands in sharp contrast to the franc's behavior during two "intervention-periods": between April 2009 and June 2010, and since January 2015, the SNB announced to prevent the Swiss franc from appreciating,[4] and increasing foreign currency reserves in its balance sheet indicate that it traded accordingly — with limited success over spring 2010 however. During these intervention-periods, the Swiss franc's volatility is muted. Note that these intervention-periods are not shaped by an explicitly communicated exchange rate target, which importantly distinguishes them from the unique "lower-bound-period" over September 2011 to January 2015. As regards the volatility of the exchange rate, it is only during the lower-bound regime that it is level-dependent: it is higher whenever EUR/CHF notes further above the lower bound of 1.20. This is exciting, because it corresponds exactly to what Krugman's (1991) model will predict.

Table (3.1) confirms the above conclusions concerning the different exchange rate regimes. The table shows least square estimates from regressing percentage changes of EUR/CHF on percentage changes of the VIX. As expected, changes in the VIX are negatively correlated with changes in the Swiss franc's price during the free-float periods. Higher global market risk implies a higher value of the Swiss franc. During the intervention-periods in contrast, VIX cannot explain EUR/CHF. Last, the VIX does explain EUR/CHF during the lower-bound-period, but coefficient estimates and R^2-measures are lower than during the free-float episodes. This conforms with the predictions of Krugman's 1991 model.

Important explanatory power of global risk factors for the Swiss franc, such as the VIX, is also documented in Griesse and Nitschka (2013), who further document increasing sen-

[3] https://data.snb.ch/en

[4] After the franc had appreciated sharply against the euro in the wake of the Global Financial Crisis in 2008, the SNB announced to *prevented the Swiss franc from appreciating further against the euro* – see the SNB's quarterly assessments of March, June, September, and December 2009, and of March 2010. Since the suspension of the Swiss franc lower bound, the SNB communicates to *take account of the exchange rate situation,* and *therefore remain active in the foreign exchange market, as necessary*: see the SNB's quarterly assessments over 2015 and 2016, https://www.snb.ch/en/iabout/pub/oecpub/id/pub_oecpub_quartbul.

sitivity of the Swiss franc to global risk in times of high uncertainty. Similarly, Ranaldo and Soderlind (2010) find that the Swiss franc appreciates systematically against the euro when global equity markets, bond markets, and currency markets signal difficult economic conditions. Kugler and Weder di Mauro (2005) document that the Swiss franc pays high returns if unexpected events that increase world-wide political uncertainty happen. Taking an asset pricing approach, Verdelhan (2011) and Hoffmann and Suter (2010) construct a global risk factor from a large cross-section of currency returns and find that this factor has important explanatory power for excess returns of the Swiss franc. All this evidence challenges the conclusion put forward by Meese and Rogoff (1983) whereby exchange rates basically are unpredictable,[5] and it supports the macroeconomic explanation of EUR/CHF we suggest in this paper within Paul Krugman's (1991) model.

3.3 A model for exchange rates within a target zone

Paul Krugman's (1991) elegant model became the starting point for much research on the economics of exchange rate target zones which was of high interest during the European Exchange Rate Mechanism (ERM) of the European Monetary System (EMS). In this system, introduced in 1979, member countries of the European Economic Community (EEC) agreed to peg their bilateral exchange rates within fluctuation bands of no more than ± 2.25 percent around central parities. However, these exchange rate bands have frequently been realigned, and after speculative attacks have urged the British pound and the Italian lira to leave the system, the German Reunification eventually triggered the collapse of the system in 1993.

For operating exchange-rate target-zones, Krugman (1991) describes a macroeconomic model in which the exchange rate is an S-shaped function of fundamentals. This function

[5]There exists a growing literature that documents that currency returns are predictable from economic fundamentals. Lustig and Verdelhan (2007), Burnside (2011) and Lustig and Verdelhan (2011) discuss the association of currency returns with consumption growth. Menkhoff et al. (2013) show that currency returns are predictable conditional on several standard macroeconomic fundamentals such as interest rate differentials, real GDP growth, real money growth, and real exchange rates, Hoffmann and Suter (2013) show that the cross-section of consumption growth rates predicts currency portfolio returns, and Jorda and Taylor (2009) find that a fundamental equilibrium exchange rate explains carry trade returns. Burnside et al. (2011a), Burnside et al. (2009), Burnside et al. (2011b), and Burnside et al. (2011c) focus on explanations of the carry trade such as investor overconfidence and peso problems. Lustig et al. (2011) show that currency portfolios that covary more heavily with global carry trade returns earn higher excess returns on average, thus compensating investors for large losses during times of global market turmoil. Menkhoff et al. (2012a) find that innovations in exchange rate volatility have explanatory power for currency portfolio returns.

obtains under two important model assumptions. First, a central bank's commitment to the target-zone must be *credible*. Credible in this context means that *markets never doubt the continuation of the lower bound*. Second, central banks must intervene in currency markets only when exchange rates effectively threaten to touch one of the edges of the band. Probably because these conditions did not hold in reality, empirical tests mostly rejected Krugman's model. In the ERM, central bank interventions were frequent also inside the band,[6] and realignments of the currency bands happened on several occasions thus rationalizing doubt on the continuation of existing currency bands. All around the world, speculative attacks frequently made exchange-rate target-zones collapse.[7]

For the Swiss franc, the situation is different. First, the Swiss National Bank has announced to defend a strong-side bound for its currency. This implies that no speculative attacks are possible that would urge a sudden realignment or a suspension of the exchange-rate bound, because a central bank can expand the monetary base of its currency without limits. Because of this, a strong-side exchange rate commitment is likely to be more credible than any weak-side commitment. Hence, a central bank can be more relaxed to let its currency float very closely to the edge of the band. Figure (4.1) suggests that the SNB did so because foreign currency reserves never increase when EUR/CHF noted above 1.20. The stability of the Swiss franc exchange rate target zone solely rests upon the willingness of the SNB to accumulate foreign exchange reserves in unlimited quantities when necessary, and to stand firm against political pressure to rise or lower the exchange rate bound. In these respects, the Swiss case is unique — the *credibility condition* (as we will argue later in more detail) and the *no-interventions-above-the-bound condition* are fulfilled such that Krugman's (1991) model applies.

3.3.1 Krugman's (1991) model

Following Krugman (1991), consider a log-linear model of the exchange rate. Expressing all variables in natural logarithms, the exchange rate s equals

[6] See for example Flood et al. (1991) or the evidence cited by Garber and Svensson (1995).

[7] Following the German unification which required a tightening of monetary policy in Germany, the European exchange rate mechanism came into crisis: in September 1992, the lira was devalued and the UK saw itself unable to halt depreciation pressure on the pound sterling and suspended its participation in the ERM. Until mid-1993, several currencies within the ERM were devalued. Eventually, after the Banque de France attempted to cut interest rates to sub-German levels, ERM fluctuation margins were widened from ± 2.25 percent to ± 15 percent in August 1993. Other prominent examples for dramatical devaluations of currencies within more or less fixed exchange rate systems include the 1994 economic crisis in Mexico, the 1997 Asian financial crisis, the Russian ruble crisis in 1998, or the Argentine economic crisis 1998-2002.

$$s_t = m_t - \kappa_t + \gamma \frac{E_t(ds_t)}{dt}. \tag{3.1}$$

where s is the spot price of foreign exchange and $E_t(\cdot)$ denotes expectation conditional on information available at time t. Further, there are two fundamentals in the exchange rate equation (3.1), the domestic money supply m and a shift term κ. Monetary policy is passive; in the case of the Swiss franc, the central bank is prepared to increase m to prevent s from falling below the announced minimum level $\underline{s}$, but as long as s notes above $\underline{s}$, money supply remains unchanged. The only exogenous source of exchange rate dynamics is the shift term κ. In Krugman's exposition of the model, κ represents a velocity shock. As we focus on the Swiss franc in its role as a safe haven currency, we specify κ to be a state variable for global market risk, whereby higher κ indicates tighter markets: higher κ implies a lower s which corresponds to a more appreciated Swiss franc against the euro.

To solve the model, assume that κ follows a continuous-time random walk

$$d\kappa_t = \mu dt + \sigma dW_t \tag{3.2}$$

where μ is a constant predictable change in κ, dW is a standard Wiener process, and σ is a constant. This assumption implies that if markets expect no changes in m, that is, if there are no specific monetary policy rules in place, there will be no predictable changes in s.

If the monetary authority announces to impose a lower limit on s, we show in the Appendix that the following general solution for the exchange rate function obtains:

$$s(m_t, \kappa_t) = (m_t - \kappa_t) + \gamma\mu + B\exp(\lambda(m_t - \kappa_t)) \tag{3.3}$$

$\lambda > 0$ is a parameter and $B > 0$ is a constant of integration. Figure (3.2) sketches this function: given m, s falls in κ. Intuitively, since market's expectation that s will increase once it notes at $\underline{s}$ enters the basic exchange rate equation (3.1), the sensitivity of s on κ declines in κ. Once persistent increases in κ have nevertheless driven the exchange rate to the lower bound, one must impose that s becomes insensitive to κ. Otherwise, changes in s conditional on κ would be predictable as the central bank will allow for increases in s only. This would give rise to arbitrage profits. Assuming central bank credibility and considering this no-arbitrage condition, the "bended" fundamental exchange rate function (3.3) results that Figure (3.2) depicts.

3.3.2 The Swiss franc's honeymoon

Figure (3.3) presents an empirical implementation of the Krugman (1991) exchange rate function (3.3) with $s = \text{EUR/CHF}$ and the VIX as the exchange rate fundamental K_{VIX}. The scatterplot of Figure (3.3) unveils the model-implied negative, non-linear relationship between K_{VIX} and EUR/CHF: the Swiss franc can be described as a falling, concave function of K_{VIX}. The figure suggests that the Swiss franc becomes less sensitive to K_{VIX} closely above the bound which is also where it clusters: in Krugman's model, exchange rates are expected to move slowly near the edge of the target zone such that – intuitively – they will appear there often.

Table (3.2) presents the results from testing the Krugman exchange rate function econometrically. The table shows least square coefficient estimates $\{\beta, \gamma, \delta\}$ and corresponding t-statistics for the following regression

$$
\begin{aligned}
\Delta s_t &= \alpha + \beta\left(\hat{S}_t \Delta \text{K}_t\right) + \gamma \Delta \text{K}_t + \delta \hat{S}_t + \varepsilon_t \\
\Delta s_t &= \alpha + \beta_1\left(\hat{S}_t \Delta \text{K}_{\text{up},t}\right) + \beta_2\left(\hat{S}_t \Delta \text{K}_{\text{down},t}\right) + \gamma \Delta \text{K}_t + \delta \hat{S}_t + \varepsilon_t
\end{aligned}
$$

where $\Delta s_t = \ln(S_t) - \ln(S_{t-1})$ are percentage changes in the EUR/CHF spot rate, and $\text{K}_t = \text{K}_{\text{VIX},t}$. The term $\hat{S}_t = (S_t - \underline{S}) = (S_t - 1.20)$ denotes the level of the actual exchange rate above its lower bound. Eventually, the above regression allows for separate slope coefficients $\beta = \{\beta_1, \beta_2\}$ for upward movements (K_{up}) and downward movements (K_{down}) of the fundamental. This specification is motivated by Lettau et al. (2013) who show that currency returns covary more strongly with aggregate market returns conditional on bad market returns than conditional on good market returns. In line with this conclusion, Table (3.2) shows that the coefficient estimate for the interaction terms, β, are significantly positive, whereby this relationship is more distinct during market downturns. The regression analysis confirms that the "loading" ($= \beta \hat{S}_t$) of the exchange rate on K_{VIX} is time-varying and increases in the actual exchange rate's distance from the lower bound, $\hat{S}_t$.

Complementary evidence that the sensitivity of the Swiss franc/euro exchange rate increases in the distance of the spot rate from its lower bound is provided by Figure (3.4). Applying the methodology proposed by Elliott and Mueller (2006) and Mueller and Petalas (2010), this Figure plots a time-varying estimate for the β_t coefficient obtained from regressing percentage changes of the spot rate, Δs_t, on $\Delta\kappa_{\text{VIX},t}$.

$$\Delta s_t = \alpha + \beta_t \Delta\kappa_{\text{VIX},t} + \varepsilon_t. \quad (3.4)$$

By the safe-haven property of the Swiss franc, we expect $\beta_t < 0$, and Krugman's (1991) model predicts lower β_t if EUR/CHF is higher. This is what we find. The quasi-local-level test (qLL test) prosed by Elliott and Mueller (2006) indicates strong parameter instability (time-variation) for β_t, and graphical inspection suggests that β_t falls in EUR/CHF: the elasticity of the Swiss franc to κ_{VIX} is higher the further away EUR/CHF notes from its lower bound.

To conclude, Krugman's (1991) model finds support by the behavior of the Swiss franc/euro exchange rate conditional on a global market risk fundamental: the SNB has sent its currency into honeymoon where it relaxed under the sunshade of market expectations that provided protection against crazy fundamentals.

3.4 Credibility

While the condition that a central bank does not change the monetary base as its exchange rate stays inside the band is easily verified and holds for the Swiss franc, the credibility condition is more difficult to assess. Because this condition is not only crucial in the framework of Krugman's model, but also interesting per se, this section examines the credibility assumption for the Swiss franc lower bound regime using financial market data.

3.4.1 Forward exchange rates

A "simple test of target zone credibility" has been proposed by Svensson (1990). Svensson noted that forward exchange rates represent expected appreciation or depreciation of exchange rates, and they must never lie outside the band in a credible target-zone regime. Otherwise, arbitrage opportunities would arise.[8] Applied to the Swiss case,

[8] Bertola and Svensson (1993) presented an extension of the Krugman (1991) model in which a state variable in addition to the exchange rate fundamental κ accounts for market's expected probability and size of a realignment of the edges of an exchange rate target-zone in operation, and for example Rose and Svensson (1995), Svensson (1993) or Lindberg et al. (1993) provide empirical implementations for different currency pairs of the ERM. Thereby, their assessment of credibility relies on the uncovered interest rate parity condition by which interest rate differentials or forward discounts should be unbiased predictors of future exchange rates.

Figure (3.5) visualizes that EUR/CHF forward exchange rates never importantly noted below EUR/CHF $= 1.20$, in particular not at levels as low as 1.10 that realized when the SNB ended the lower-bound era. Hence, in retrospect, Svensson's (1990) test broadly confirms that markets have taken the SNB's lower-bound-commitment for granted. But qualifying this result, Campa and Chang (1996, 1998), or Malz (1996, 1997b) noted that higher moments of the exchange rate distribution are more informative about market's expectations. Currency option prices not only inform about the mean, but also about the variance, skewness and kurtosis of the expected exchange rate distribution function. This can inform about the probability which markets assign to the continuation of an exchange-rate target zone in place.

3.4.2 Over-the-counter (OTC) option price quotes

Prices of different option contracts imply a probability density function for future exchange rate realizations. The option price quotes that are readily available in over-the-counter markets are the at-the-money implied volatility price, the risk-reversal price, and the strangle price. These are prices of particular option portfolios which are described in the Appendix. It is convenient to focus on these three prices, because they summarize the distribution of the exchange rate function which they imply. In particular, the at-the-money implied volatility indicates the overall level, the risk-reversal indicates the skewness, and the strangle volatility price indicates the kurtosis of the option-prices implied exchange rate distribution. Note that this distribution is a risk-neutral distribution, which means that it puts more weight on exchange rate values which markets fear.[9] But even if — or rather because — this option-implied exchange rate distribution function does not mirror "true" expectations, but "feared" expectations, it importantly informs about market sentiment.

Figure (3.6) shows time series of the EUR/CHF at-the-money implied volatility (ATM), the 25-delta risk-reversal (RR), and of the 25-delta strangle (STR) over the lower-bound regime.[10] Negative risk-reversal prices indicate appreciation pressure on the Swiss franc against the euro, and high strangle prices indicate that markets put high probability on a large jump of the exchange rate in either direction.

[9]As an example, consider a EUR/CHF call option with a relatively high exercise price. A long position in such a contract insures against a loss from a Swiss franc appreciation. If markets fear such an appreciation, demand for this option contract will be high which increases its price. In that case, the risk-neutral probability for a Swiss franc appreciation will turn out to be higher than the probability that traders effectively assign to it.

[10]The option delta indicates how far an option is in-the-money, or out-of-the money. See the Appendix for further explanation.

For the days during spring 2012 when EUR/CHF was sticky at 1.20, the 25-delta RR-prices allow for a direct assessment of the perceived stability of the Swiss franc minimum exchange rate. During these days, this RR prices would have been zero or positive if all market participants would have expected that one euro will always be exchangeable for 1.20 Swiss francs in the spot market. Alas, Figure (3.6) unveils that this did not hold true. In addition, high STR prices indicate that some market participants indeed expected a large move of EUR/CHF. When the banking crisis and the sovereign debt crisis hit Europe unprepared in spring 2012, RR-prices unveil that even the SNB's market interventions could not halt appreciation pressure on the franc beyond 1.20 to the euro. However, it is not clear whether this appreciation pressure has primarily been driven by doubt of whether the SNB was truly "prepared to buy foreign currencies in unlimited quantities",[11] or whether increasing global risk aversion and fear of a break-up of the Eurozone rather explain it. Support for this latter interpretation is given by the fact that it was actions taken by the European Central Bank that eased appreciation pressure on the franc, and not policy steps undertaken by the SNB. Following Draghi's "whatever-it-takes" statement at the end of July 2012[12] and the launch of the Outright Monetary Transaction (OMT) program[13] on 6 September 2012, prospects for the euro improved and EUR/CHF RR-prices increased.

The EUR/CHF spot exchange rate and RR-prices fell again over November 2014. While the above narrative suggests that appreciation pressure on the franc during 2012 sourced in demand for insurance that Swiss francs could provide when the future of the euro was uncertain, this time, appreciation pressure is likely more related to markets expecting a soon end of the lower-bound policy. This was triggered by rumors that the ECB was considering large-scale open market transactions, which inevitably induces appreciation pressure on the franc vis-à-vis the euro.[14] But in December, the SNB started to target negative LIBOR rates and could convince markets again that it will always defend EUR/CHF $= 1.20$.[15] Having regained credibility, the SNB's suspension of the lower

[11] SNB Quarterly Bulletin of March 2012

[12] In July 2012, Mario Draghi, president of the European Central Bank, unambiguously stated that the ECB will be "...ready to do whatever it takes to preserve the euro". Follow for example this link: http://www.youtube.com/watch?v=Pq1V0aPE03c. At the beginning of September 2012, the publication details for the Outright Monetary Transaction (OMT) program further calmed markets, http://www.ecb.europa.eu/press/pr/date/2012/html/pr120906_1.en.html.

[13] The Outright Monetary Transaction (OMT) program allows the ECB to buy government-issued bonds on secondary markets to provide liquidity to countries that face problems selling their debt. For details, follow http://www.ecb.europa.eu/press/pr/date/2012/html/pr120906_1.en.html

[14] see for example this Reuters news: http://uk.reuters.com/article/uk-ecb-qe-idUKKCN0IT0KX20141109

[15] See the SNB Quarterly Bulletin of 11 December 2014, https://www.snb.ch/en/iabout/pub/oecpub/id/pub_oecpub_quartbul

bound one month later came as a surprise — option prices, together with the sharp fall of EUR/CHF on 15 January 2015, tell that markets didn't anticipate this to happen.

3.4.3 Appreciation pressure on the franc at 1.20: "global risk aversion" vs "lack of credibility"?

While risk-reversal prices and strangle prices with constant delta indicate appreciation pressure and uncertainty for EUR/CHF independent of the actual level of the exchange rate, the trajectory of the price of EUR/CHF option contracts with a constant strike of $K = 1.20$ can inform about appreciation expectations of the franc beyond 1.20 to the euro also when EUR/CHF noted above 1.20. Option prices for given strike prices are not quoted in the market, but the Appendix shows how to obtain them from ATM, RR, and STR prices with constand delta.

Consider the price of an European EUR/CHF put options that entitles its holder to sell one euro for $K = 1.20$ Swiss francs in τ =one month time:[16]

$$P(K,\tau) \quad = \quad \frac{1}{1+i_\tau}\int_0^K (K - S_\tau(\kappa_\tau))f(S_\tau)dS_\tau \tag{3.5}$$

In the following, the price of this put contract is denoted by P(1.20). This option contract is in-the-money (has a positive price) only if $E(S_\tau) < K$, that is, if $E(\text{EUR/CHF}_\tau) < 1.20$. Strictly speaking, in a credible lower-bound exchange rate regime, such a put option contract must never have a positive price. But the panel in the middle of Figure (3.7) unveils that P(1.20) has been high at various instances. Figure (B.1) in the Appendix suggests that the probability for $S_\tau < 1.20$ has repeatedly been as high as $30\% - 40\%$, and even positive for $S_\tau < 1.10$ over spring 2012. But in the above section, we have argued that the then observed high prices for put contracts with strikes below EUR/CHF $= 1.20$ likely resulted from fear of the euro falling apart. In contrast, we argue that over November 2014, the SNB was indeed confronted with a credibility problem. The following paragraphs elaborate on this presumption.

This paper describes the Swiss franc as a safe haven currency, that is, as a function of global risk fundamentals such as the VIX. Credibility of the lower bound implies that the

[16] Hanke et al. (2016) summarize that because short-term interest rates on the Swiss franc have been close to zero and consistently below euro interest rates, an American EUR/CHF put option should never be exercised early, which makes its price equal to that of a European put option (see Hanke et al. (2016) on page 10, or the argumentation in Hanke et al. (2015)).

sensitivity of the franc to its global risk fundamentals is zero at the bound and increases in the distance of the spot rate from the bound: the announcement to always defend EUR/CHF $= 1.20$ has muted the safe haven property of the Swiss franc. This obtains without any foreign exchange market transactions by the SNB, as long as EUR/CHF notes above 1.20. Over spring 2012 and fall 2014 in contrast, EUR/CHF was sticky at 1.20, and it did not fall further because the SNB enforced it. By trading to stabilize EUR/CHF at 1.20, the SNB completely suspended the safe haven behavior of the Swiss franc spot exchange rate because it let not market forces determine its price. But in contrast to the spot exchange rate, this central bank trading could not suspend the safe haven characteristics of EUR/CHF option prices, as Figure (3.7) unveils. The middle and the lower plot of this figure show that P(1.20) strongly co-moves with VIX, also when EUR/CHF noted at the bound. This safe haven behavior of EUR/CHF option prices, which apparently is not (completely) suspended by the Swiss franc lower bound, allows to shed light on whether *global*, or *Swiss franc specific* factors lie at the source of Swiss franc appreciation pressure. Whenever P(1.20) and VIX-global-risk-aversion spike at the same time, appreciation pressure on the Swiss franc is likely driven by global market risk and not by Swiss franc specific issues such as “SNB credibility”. Confirming the conclusion derived from RR prices, P(1.20) sharply increased absent a corresponding peak in VIX only over fall 2014. We conclude that this identifies the single severe instance of low SNB credibility.

identifying credibility independent of global risk aversion

We have argued that P(1.20) can be driven by both, global risk aversion and expectation of a soon end of the Swiss franc lower bound regime. The upper plot of Figure (3.7) attempts to distinguish these two sources of appreciation pressure on the Swiss franc. The figure presents the scores of the two principal components constructed from the global risk exchange rate fundamental $K_{VIX} =$ VIX, and P(1.20). While building principal components is a purely technical method to separate orthogonal factors from correlated variables, we can assign both factors an obvious interpretation here. The first principal component loads positively on both, VIX and P(1.20), and it explains three quarters of the total variance. Clearly, this factor mirrors broad global market sentiment. The trajectory of the second factor however suggests an interpretation in terms of credibility or *mistrust*. By construction, and by the obvious interpretation of the first principal component, this factor is unrelated to overall market risk. In more detail, this factor is high over 2012, but a clear single spike is also visible in fall 2014. To conclude, this factor analysis adds evidence that doubt in the continuation of the lower bound regime, that sourced in a potential decision of the SNB in the first place (and not in a break-up of the Eurozone for example), only arose during November 2014.

macroeconomic explanation of EUR/CHF option prices

In the Krugman (1991) model, appreciation pressure on the franc beyond 1.20 to the euro never occurs. This framework predicts that the safe haven property of the Swiss franc — its systematic co-movement with variables that mirror global market tension — gradually vanishes as the franc approaches the lower bound. But evidence presented above suggests that the model-conform behavior of EUR/CHF was on hold during spring 2012 and November 2014, as the Swiss franc was insensitive to K_{VIX} only because the SNB enforced it, and not because of model-conform expectations. In particular, EUR/CHF option prices (P(1.20)) display a safe haven behavior over the spring 2012 episode. But during the other months of the lower bound regime, P(1.20) should be a non-linear function of K_{VIX} too, because it is monotone in the value of the underlying EUR/CHF exchange rate. This finds support in Figure (3.8) that plots the negative of P(1.20) against VIX: most observations align on a Krugman (1991) model type “bended honeymoon curve” in the P(1.20) and K_{VIX} space. The spring 2012 interruption of the Swiss franc’s honeymoon is clearly visible by the observations marked as red dots which lie as outliers “far below the bended curve”. The same is observed for the November 2014 episode (green circles). Both episodes are characterized by doubt about the continuation of the lower bound, which — as we argue — is due to high global market risk in the first case, and to effective doubt on the SNB’s readiness to continue the lower bound regime in the second case. Interestingly, the observations of P(1.20) and VIX for the final days of the lower bound regime are perfectly in line with the predictions of Krugman’s model. Table (3.3) shows least square coefficient estimates from regressing percentage changes of P(1.20) on percentage changes of K_{VIX}, interacted with the level of EUR/CHF above the lower bound. As for the EUR/CHF spot rate, the results confirm that the safe haven behavior of P(1.20) declines as the spot rate approaches the lower bound. The further above the lower bound the Swiss franc notes, the more does P(1.20) increase if global risk, VIX, increases.

3.5 Related literature

The present paper continues our earlier working-paper version available as Studer-Suter and Janssen (2014); to the best of our knowledge, we were the first to relate to Paul Krugman’s (1991) ideas to describe the Swiss franc lower bound episode. But meanwhile, our approach and our results are closely related to the findings of a series of recent papers: in a nutshell, the literature concludes that EUR/CHF tends to be distributed as Krugman's (1991) model predicts (Hertrich, 2016b), and credibility of the SNB's regime has been low over the initial months of the lower-bound regime, but increased until summer 2014, when it started to decline again. All studies agree that EUR/CHF would have been much lower than 1.20 during the 2012 outbreak of the European sovereign debt crisis, but only two papers (Hertrich, 2016a and Hertrich and Zimmermann, 2015) conclude that the SNB's credibility was weak during that time. Eventually, the literature concludes that the SNB ended the lower-bound regime at a point in time when markets' doubt was high.

A log-linear model for the exchange rate forms the starting point of most studies on exchange rate target zones, which is also common in finance. But in this framework, the only recent publication that takes our way and uses macroeconomic fundamentals to explain EUR/CHF is Hui et al. (2016): these authors find that the drift coefficient in the equation for the fundamental — that corresponds to μ in equation (3.2) of this paper — increases in foreign exchange reserves which pushes EUR/CHF away from the strong-side limit. Time-variation in μ can be interpreted as variability in credibility.

A series of papers decomposes the log-linear process for the exchange rate into a "fundamental" or "latent" exchange rate, that is, the exchange rate that would have prevailed in absence of the lower bound, plus a "guarantee"[17] which is the value of the SNB's commitment to prevent the franc from appreciating beyond 1.20 to the euro. Jermann (2016) describes a model in which this guarantee is determined by the expected continuation probability of the lower-bound regime at a given horizon, and he applies his model to price currency options conditional on the model-implied exchange rate process. Hanke et al. (2015) and Hanke et al. (2016) view the SNB's guarantee as a put option to sell euros for 1.20 Swiss francs, and in addition to a latent process for the exchange rate, they derive measures for the market's expected remaining lifetime of the lower-bound regime: they find that credibility increased between summer 2012 and summer 2014, but then started to fall again which suggests that markets had anticipated the end of the lower-bound era. Hertrich (2016a) proposes to model EUR/CHF as a reflected geometric Brownian motion, as in Veestraeten (2013). His estimate of the process for the latent EUR/CHF exchange rate resembles those of the contributions cited above, but he interprets the difference between the latent (implied by their option pricing model) and the observed exchange rate as a measure of the costs the SNB had to bear to sustain the lower bound regime. This suggests to conclude that credibility has been low during the

[17] we like this term which is borrowed from Hanke et al. (2016)

2012 outbreak of the European crisis, which stands in contrast to the interpretations of the other papers cited above.

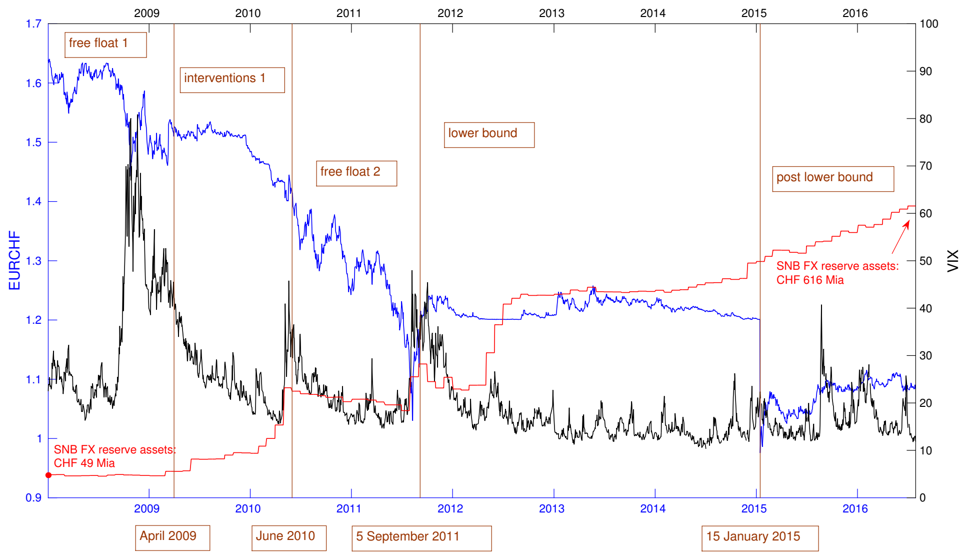
Hertrich (2016b) adapts the target-zone model by Chen and Giovannini (1992) to allow for estimates of the unconditional distribution of EUR/CHF in its one-sided target-zone. He finds that EUR/CHF is asymmetric and right-skewed which corresponds to what the Krugman (1991) model predicts, and which reaffirms that the SNB intervened in currency markets only at the lower bound, and not above it. The second crucial assumption of Krugman's (1991) model, which is the credibility assumption, is the main focus of Hertrich and Zimmermann (2015). These authors specify a currency option pricing model which applies to exchange rates in one-sided target zones; in this model, the exchange rate follows a Brownian motion as in the standard Garman and Kohlhagen (1983) model, which our qualitative results are based on, but the process has a reflecting barrier in addition. If correctly specified, this model allows for quantitative estimates of option-implied probabilities for future EUR/CHF rates below the bound. While the evolution of credibility corresponds to the finding of other papers — low at the beginning, potentially low during spring 2012, and falling since summer 2014 — these authors conclude that the SNB's policy stance has never been credible: they state that in a credible lower-bound regime, EUR/CHF put option prices must not trade at any positive price. Our paper responds to this by arguing that much of the appreciation pressure on the Swiss franc was rather not related to speculation on a suspension of the lower bound, but related to safe haven demand during times of high global market uncertainty. This is the strength of the macroeconomic approach to the exchange rate — it allows for interpretations.

The macroeconomic approach of this paper starts from the notion of the Swiss franc as a safe haven currency, and it documents high explanatory power of the VIX for EUR/CHF, which is a common measure of global market sentiment.

3.6 Conclusion

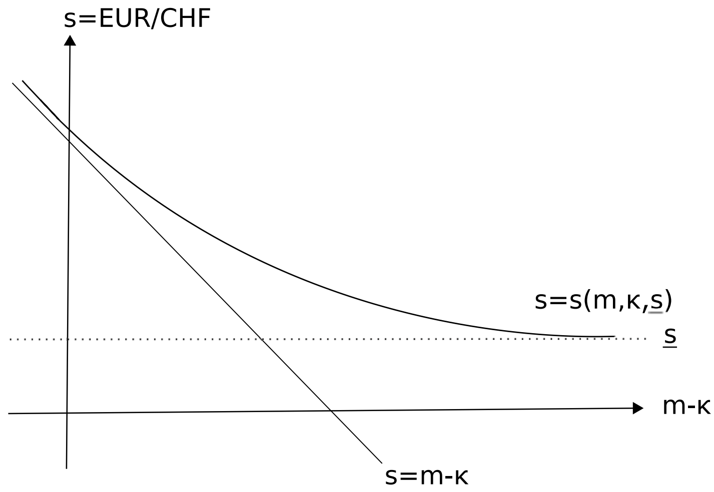
Starting from the stylized fact that the Swiss franc is a safe haven currency, this paper retrieves the macroeconomic model outlined by Krugman (1991) to describe the EUR/CHF exchange rate as a function of global market risk fundamentals, which is the VIX in particular. During most of the Swiss franc lower bound regime, that was in operation between September 2011 and January 2015, EUR/CHF behaved conforming with the predictions of Krugman's model: the sole expectation that the Swiss National Bank will prevent the Swiss franc from appreciating beyond 1.20 to the euro has muted the sensitivity of EUR/CHF to global market risk. The Swiss franc was in honeymoon. In the model, this obtains because the central bank is assumed to be credible. The second part of this paper assesses this crucial assumption. Analyzing the co-movement of EUR/CHF option prices and global market risk, we conclude that though markets doubted the continuation of the existing EUR/CHF exchange rate policy when the European sovereign debt crisis put the continuation of the euro into question during spring 2012, SNB credibility was a true issue only in November 2014. Alas, after markets had doubted the SNB's willingness to continue the lower bound regime for the first time, the Swiss central bank could convince markets anew from its target-zone policy in December 2014. A few weeks later, the SNB unexpectedly suspended the lower bound. To conclude, this paper supports Krugman's (1991) model for EUR/CHF during the Swiss franc lower bound episode. This is remarkable since a large literature rather rejected versions of this model. But here, this simple, though elegant approach can explain how the Swiss franc's value was determined by its global risk fundamentals inside the recent target-zone.

Figure 3.1: EUR/CHF, VIX, SNB foreign currency reserve assets



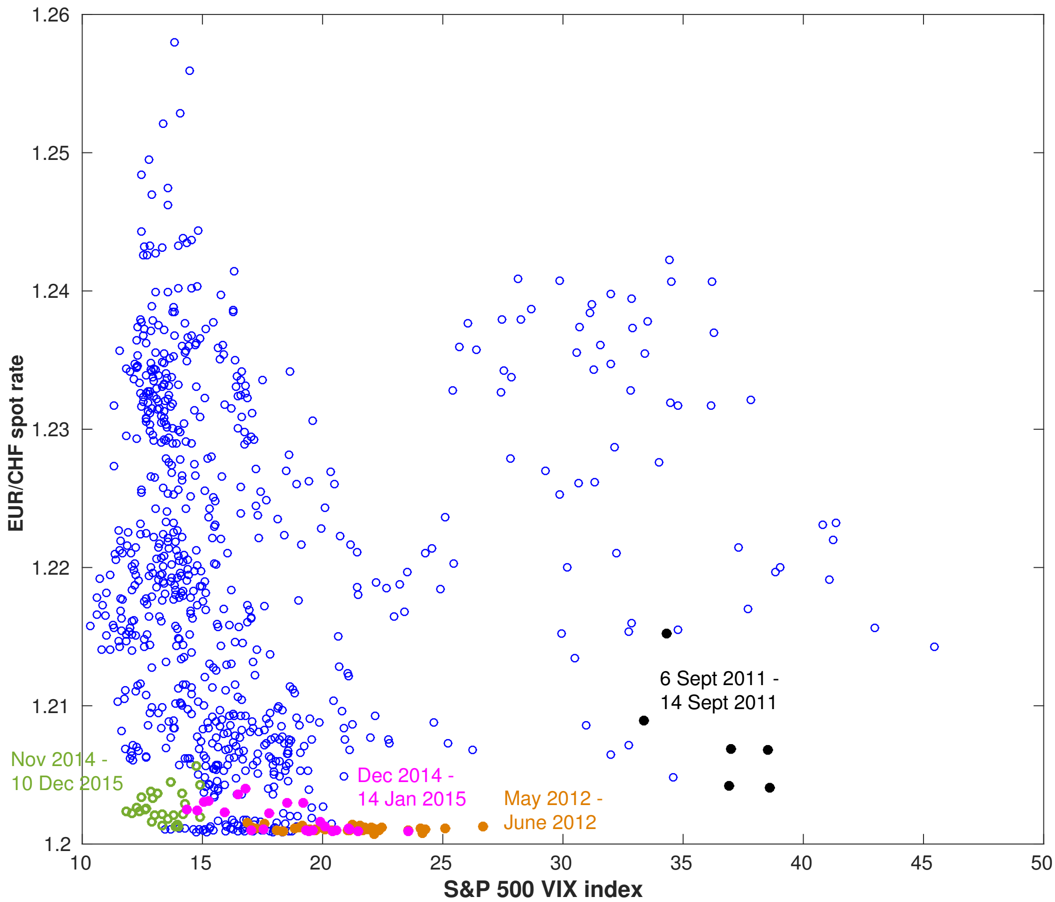
The blue graph (left axis) shows the Swiss franc/euro spot exchange rate expressed in numbers of Swiss francs per one euro, and the black graph (right axis) shows the S&P 500 options implied volatility index VIX. The red graph (right axis) indicates the Swiss National Bank's foreign currency reserve assets measured in 10 Mia of Swiss francs. Based on the SNB's communicated policy stance and on the evolvement of its foreign currency reserves, the figure distinguishes five different monetary policy regimes which are characterized by the volatility of the EUR/CHF exchange rate, given the volatility of global markets as measured by the VIX index. Exchange rate observations and the VIX index are daily, SNB reserve holdings are reported monthly.

Figure 3.2: Sketch of the Krugman (1991) exchange rate function



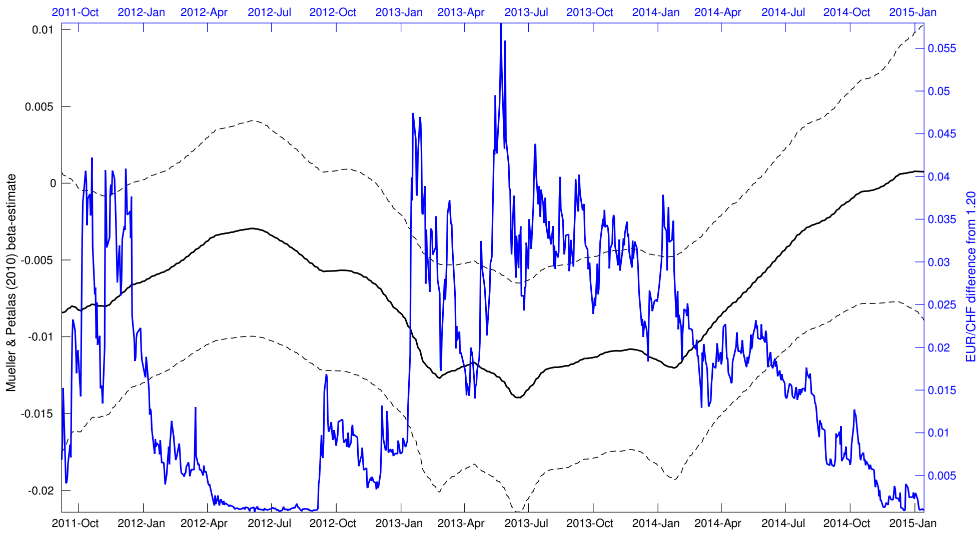
This figure sketches the Krugman (1991) functional relationship of the spot exchange rate s and currency market fundamentals κ, m applied to the one-sided target zone regime of the sort that the Swiss National Bank enforced for the Swiss franc against the euro between September 2011 and January 2015. The existence of the lower bound $\underline{s}$ implies a lower bound for the fundamental $(\underline{m-\kappa})$, where m is the monetary base and κ are other currency market fundamentals reflecting foreign exchange supply and demand. As s approaches the lower bound, it becomes insensitive to changes in the fundamentals.

Figure 3.3: EUR/CHF, a function of κ_{VIX}



The figure plots each observation of the Swiss franc/euro exchange rate against the same day's value of the S&P 500 options implied volatility index VIX. The data is at daily frequency and includes all days that were trading days in Switzerland and the US, and for which observations of the VIX index are available.

Figure 3.4: Time-varying sensitivity (β) of EUR/CHF on $\mathrm{K}_{\mathrm{VIX}}$

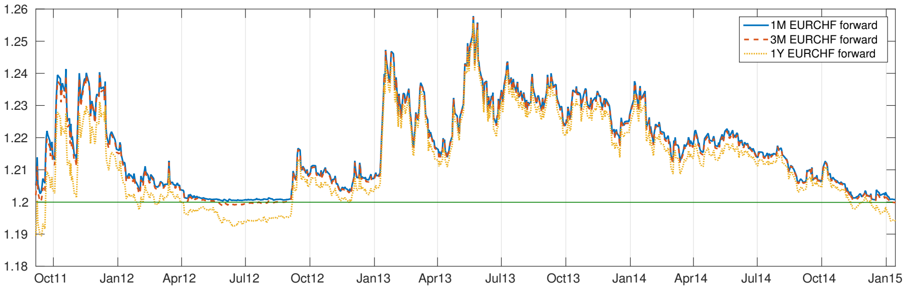


Applying the method proposed by Elliott and Mueller (2006) and Mueller and Petalas (2010), the black line (left axis) shows time-varying estimates of the β_t- coefficient of the following regression equation

$$\Delta s_t \quad = \quad \alpha + \beta_t \mathrm{K}_t + \varepsilon_t$$

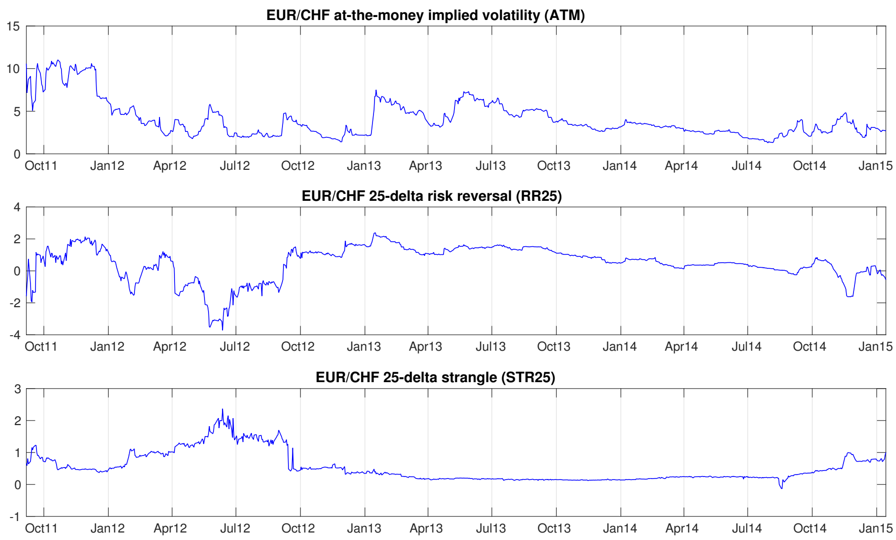
where Δs_t denote percentage changes in the EUR/CHF spot exchange rate, α denotes a constant and $\mathrm{K}_t = \ln(\mathrm{VIX}_t) - \ln(\mathrm{VIX}_{t-1})$ is the exchange rate fundamental. The thin, dotted lines depict 95% confidence intervals for the β_t-estimates. The blue line (right axis) shows the distance of $\mathrm{EUR/CHF}_t$ from the lower bound of 1.20. The data is at daily frequency and includes all days that were trading days in Switzerland as well as in the US, and for which the VIX is available.

Figure 3.5: EUR/CHF outright forward exchange rates



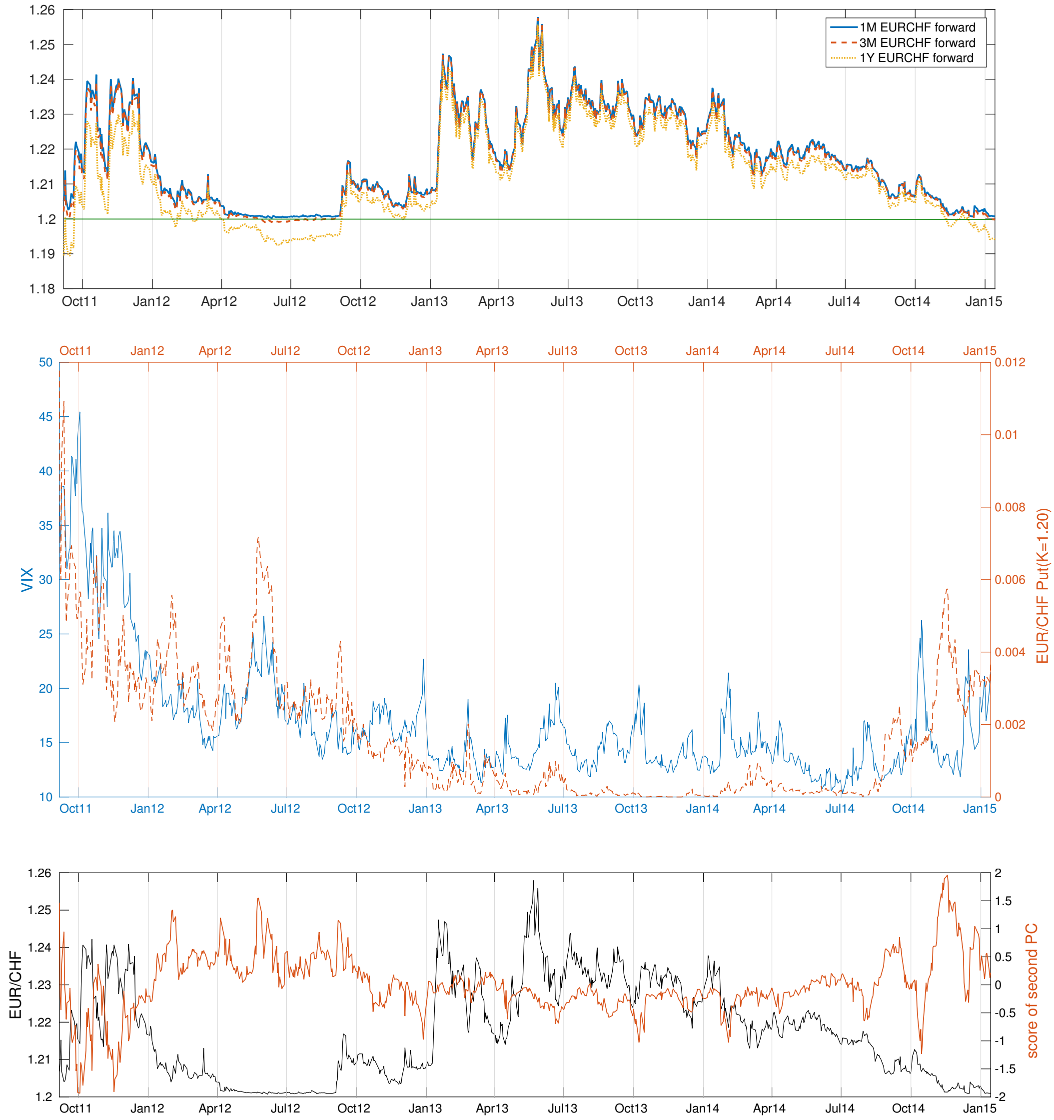
The figure shows EUR/CHF forward outright exchange rates for 1 month, 3 months, and 12 months maturity. The data is daily and encompasses all days that were trading days in the US and Switzerland between mid September 2011 and mid January 2015.

Figure 3.6: OTC EUR/CHF option price quotes



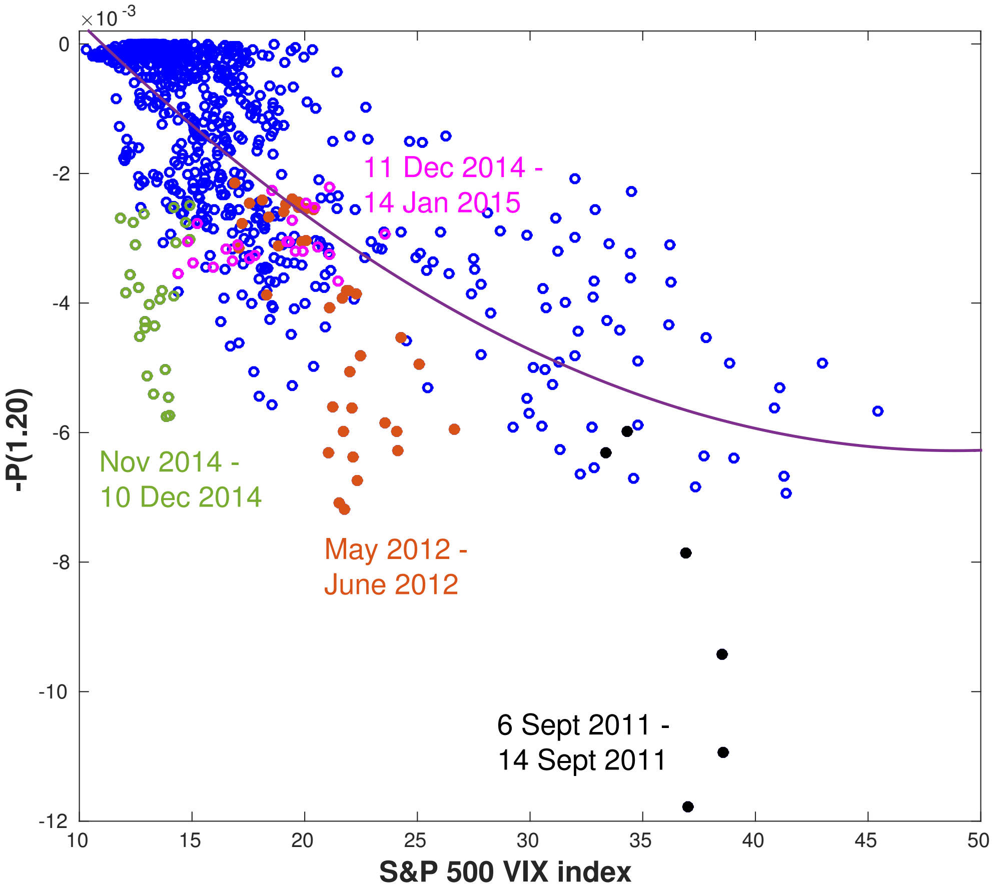
The figure shows time-series plots of the volatility price of three different EUR/CHF option contracts. A description of these contracts is given in the Appendix. All option contracts have a maturity of one month, the data is at daily frequency and encompasses all days that were trading days in Switzerland and the US.

Figure 3.7: A factor for global risk and a credibility-factor



The upper figure plots the scores of the two principal components of the a) S&P 500 options implied volatility index VIX and of b) the price for an EUR/CHF put option with a strike price of 1.20 and a time-to-maturity of one month, denoted P(1.20) in this paper. Principal components are constructed from the correlation matrix of the two variables. The put option price is obtained by interpolating the volatility smile, the Appendix describes further details. The blue graph shows the score of the first principal component which explains 85% of the variance in the data, and the red graph depicts the score of the second principal component (both left axis). The black, dotted graph indicates the Swiss National Bank's currency reserve assets in CHF millions (right axis). The middle plot shows the two variables the principal components are derived from, the VIX and P(1.20). The plot at the bottom shows the score of the second principal component again together with EUR/CHF.

Figure 3.8: P(1.20)against its global risk fundamental K_{VIX}



The figure plots ths S&P 500 options implied volatility index VIX against the negative of the price of an EUR/CHF put option with a strike of 1.20 and one month time to maturity, denoted by P(1.20) in this paper. Put prices are obtained from the interpolated risk-neutral density function for the Swiss franc prices of one euro as suggested by Malz (1997a), details are described in the Appendix. The purple line displays the best fitting quadric polynomial with $y = \text{P}(1.20)$ and $x = \text{VIX}$. The data is at daily frequency and includes all days that were trading days in Switzerland and the US.

Table 3.1: EUR/CHF explained by VIX-measured global market risk

	JAN 2008 - MAR 2009	APR 2009 - MAY 2010	JUN 2010-AUG 2011	SEPT 2011 - JAN 2015	JAN 2015 -JUL 2016
ΔVIX	-0.0429^*	-0.0072	-0.0488^*	-0.0072^*	-0.0057
	(-10.6546)	(-1.7326)	(-7.2298)	(-6.0061)	(-1.7347)
CONST	-0.0000	-0.0002	-0.0005	0.0000	0.0002
	(-0.0517)	(-1.4239)	(-1.0799)	(0.1391)	(1.1680)
R^2	0.30	0.03	0.19	0.06	0.01
NOBS	302	279	304	814	380

The table reports coefficient estimates and corresponding t-statistics from regressing percentage changes in EUR/CHF on percentage changes in the VIX. T-statistics are calculated from a HAC-consisten covariance matrix according to Newey and West (1987) and Newey and West (1994). Generally speaking, an increasing VIX indicates "bad days". The Swiss franc is a safe haven currency because it systematically appreciates against the euro (and other currencies) whenever VIX increases. The data is at daily frequency and covers all days that were trading days in the US and Switzerland, and for which the VIX is available (some few dates are missing). The complete sample spans the period from 3 January 2008 to 29 July 2016.

Table 3.2: EUR/CHF as a function of K_{VIX} during the lower bound regime (SEPT 2011 - JAN 2015)

$(\Delta\text{VIX} : \Delta\text{VIX} > 0) \times \hat{S}$	-0.4708^*	$(\Delta\text{VIX}) \times \hat{S}$	-0.3816^*
	(-4.6191)		(-4.0971)
$(\Delta\text{VIX} : \Delta\text{VIX} < 0) \times \hat{S}$	-0.1984		
	(-1.3620)		
ΔVIX	-0.0009		-0.0008
	(-0.7610)		(-0.6559)
$\hat{S}$	-0.0094		-0.0149^*
	(-1.3958)		(-2.6345)
CONST	0.0003^*		0.0003^*
	(3.2080)		(3.0755)
R^2	0.09		0.09
NOBS	814		814

The table reports coefficient estimates and corresponding t-statistics from regressing percentage changes in EUR/CHF on percentage changes of the S&P 500 options implied volatility index VIX. T-statistics are calculated from a HAC-consisten covariance matrix according to Newey and West (1987) and Newey and West (1994). $\hat{S} = S - 1.20$ denotes the deviation of EUR/CHF from the lower bound. The data is at daily frequency and covers all days that were trading days in the US and Switzerland, and for which data for the VIX is available (some few days are missing). The data covers the period from 6 September 2011 to 14 January 2015.

Table 3.3: P(1.20) as a function of K_{VIX}

dependent variable: ΔP(1.20)						
ΔVIX $\times \hat{S}$	ΔVIX	$\hat{S}$	Δs	CONST	R^2	NOBS
88.3188*	−0.3816	6.1467*	−121.9785*	−0.0167	0.33	814
(3.5119)	(−1.4336)	(4.2790)	(−6.4099)	(−0.8877)		
	1.0452*	6.4437*	−127.7677*	−0.0204	0.31	814
	(3.8589)	(4.3005)	(−6.4993)	(−1.0428		

The table shows least square coefficient estimates from regressing percentage changes of P(1.20), which denotes the price of a EUR/CHF put option contract with a strike of 1.20 and a time-to-maturity of 1 month, on percentage changes in the VIX. In the model presented in the first two rows (coefficient estimates and t-statistics below), changes in VIX are also interacted with the distance of EUR/CHF from the lower bound, $\hat{S} = \text{EUR/CHF} - 1.20$. The put prices are obtained by interpolating the volatility smile as suggested by Malz (1997a), details are described in the Appendix. T-statistics for the least squares estimates are calculated from a HAC-consisten co-variance matrix according to Newey and West (1987) and Newey and West (1994). The data is at daily frequency and covers all days that were trading days in the US and Switzerland, and for which data for the VIX is available (some few days are missing). The data covers the period from 6 September 2011 to 14 January 2015.

Chapter 4

Not that puzzling: consumption and relative prices within the EMU

Not that puzzling: consumption and relative prices within the EMU

Rahel Studer

Abstract

Monthly retail sales data and consumer price inflation support the predictions of a complete markets model with nontraded goods: within the Eurozone, countries with below average consumption growth tend to have appreciating real exchange rates. Thereby, goods that are rather characterized as nontradeable across locations explain relatively larger shares of the variance of the real exchange rate between individual countries and the Eurozone, as the traded-nontraded goods model for the real exchange rate predicts. The monotone relationship between consumption growth and real appreciation is particularly clear for portfolios built along countries' consumption growth. This inspires the interpretation of exchange rate returns from an asset pricing perspective. This paper puts into perspective the limits of the classical international macroeconomic model which the Backus and Smith (1993) puzzle highlights.

JEL Classification Numbers: E21, E31, F31, F36

Keywords: real exchange rate, retail price index, consumer price index, segmented goods markets, EMU, consumption growth

4.1 Introduction

This paper addresses the consumption – real exchange rate puzzle of Backus and Smith (1993) and Kollmann (1995). Standard international macroeconomic models in which agents have constant relative risk aversion preferences predict that countries with relatively low consumption growth should have appreciating real exchange rates. If financial markets are incomplete, the same relationship approximatively holds in expectations.[1] In this context, the low, and often negative, correlation between real exchange rates and relative consumption growth rates which economists commonly observe is surprising, and it shows the limits of state of the art macroeconomic models. But in this paper, I argue that within the Eurozone, where the common currency eliminates all fluctuations in nominal exchange rates, changes in real exchange rates co-move with countries' relative consumption growth rates quite in line with the classical prediction. Figure (4.1) shows that over time, as well as in the cross section, countries with relatively low consumption growth tend to have appreciating real exchange rates. Thereby, this negative relationship between consumption growth and price growth not only holds on average — in expectations —, but the part of the figure that pools all individual "consumption growth – price growth" observations indicates such a negative relationship as well. Further, for each country individually, time series graphs in the lower plot of Figure (4.1) shows that relative prices tend to co-move negatively with relative consumption: relative prices tend to increase (fall), whenever relative consumption growth rates are small (large). Here, consumption growth and corresponding inflation rates are approximated by monthly total retail sales data for the *old Eurozone countries* which are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain, over January 2001 to December 2015. This paper chooses an empirical approach to shed light on an important exchange rate puzzle and it concludes that within the Eurozone, relative prices adjust to relative consumption towards the model's equilibrium allocations. The joint behavior of relative prices and relative consumption is not that puzzling.

Backus and Smith (1993) consider a complete markets model with frictions in goods markets. Goods markets segmentation induces differences in marginal utility growth across countries which are balanced by real exchange rate adjustments, $\Delta q = m^k - m^h$. Following the classical Salter (1959)- and Swan (1960) dichotomy of *traded* (T) and *nontraded* (N) goods, segmented goods markets are modeled by letting agents consume a bundle composed of an internationally traded consumption good and a nontradeable consumption good. While PPP is assumed to hold for the traded good, country-specific

[1] see Kollmann (1995) for example.

endowment shocks in the nontraded goods sector induce variation in the relative prices of nontraded goods across countries which accounts for changes in the real exchange rate (the TNT-model for the real exchange rate). In equilibrium, a country's real exchange rate appreciates whenever it suffers from low consumption growth (the consumption real exchange rate correlation hypothesis).

A vast literature elaborates on international macroeconomic models to endogenously generate low consumption-real exchange rate correlations. Other studies attempt to identify why relative consumption and exchange rates contradict the model's equilibrium allocation. In this spirit, Hess and Shin (2010) or Devereux and Hnatkovska (2014) attribute the consumption-real exchange rate anomaly to the behavior of the nominal exchange rate which is reminiscent of the uncovered interest rate (UIP) puzzle: currencies of countries with high interest rates should depreciate as should the currencies of countries with high consumption growth — but they typically don't. Other authors, for example Crucini and Landry (2012), argue that aggregated data blur the true relationship between goods consumed and their prices and show that it is helpful to zoom in on disaggregated data to discover that goods level real exchange rates appreciate whenever consumption of this good is relatively low. These insights form the basis of my paper: I use data for the Eurozone, where the nominal exchange rate is fixed, at a quite disaggregated level and at high (monthly) frequency to explore whether real exchange rate fluctuations do shift purchasing power to countries with low consumption growth, and whether this can be attributed to relative quantities and prices of nontraded goods. I find support for the TNT-model and for the consumption real exchange rate correlation hypothesis. For example, I find that a one percent decline in the growth rate of retail sales of health products in one country relative to the Eurozone average comes along with an appreciation of its corresponding terms of trades of 0.5 percent, see Table (4.3).

The remainder of this paper is structured as follows: the next section presents a version of the complete markets model with nontraded goods. Section (4.3) relates this paper to the literature. Section (4.4) discusses how to measure "traded" and "nontraded" goods and their prices and presents the data. Section (4.5) shows that relative inflation rates of consumer prices sub-indexes support the TNT-model for the real exchange rate: goods that commonly are classified as nontradeable explain the variance of the aggregate real exchange rate more than their relative weight in the overall CPI. Eventually, Section (4.6) and (4.7) present evidence for the exchange rate consumption correlation hypothesis. While Section (4.6) analyzes the joint behavior of relative prices and relative consumption (retail sales) in the panel and at the country level over time, Section (4.7) focuses on risk-sharing in the cross-section. A portfolio analysis allows to build synthesized, artificial countries with constantly high or low consumption growth (= country portfolios), and I find that high (low) growth country portfolios have systematically depreciating (appreciating) real exchange rates. An outlook on further research discusses the systematic appreciation of low consumption growth countries/portfolios from an asset pricing perspective. Section (4.8) concludes.

4.2 The model

Consider a two-period complete markets model. There are K countries which, at the beginning of the second period, receive a stochastic endowment of a homogeneous traded good, Y_T, and of a country-specific nontraded good, Y_N^k. Assume that the state space in the second period is finite, and ω describes the realized history of states. In the first period, endowments are not stochastic. Endowments cannot be stored but must be consumed in the period in which they were received. Households maximize lifetime utility:

$$U_1^k = \frac{1}{1-\gamma}\left(C_1^k\right)^{(1-\gamma)} + e^{-\delta}\frac{1}{1-\gamma}E\left[\left(C_2^k\right)^{(1-\gamma)}\right]. \tag{4.1}$$

C_t^k is the consumption index for country k at time t which is composed of tradeable and nontradeable consumption according to

$$C_t^k = g(C_{T,t}^k, C_{N,t}^k) \equiv \left(\left(\tau C_{T,t}^k\right)^{\alpha} + (1-\tau)\left(C_{N,t}^k\right)^{\alpha}\right)^{\frac{1}{\alpha}} \tag{4.2}$$

where C_N is consumption of the country-specific non-traded good, C_T stands for consumption of the internationally traded good, τ is the weight of the traded good in the consumption index. Eventually, $1/(1-\alpha)$ is the elasticity of substitution between internationally traded and the local nontraded good.

Define the real exchange rate as the price of one unit of country k's in units of a "home" or "base" country's goods

$$Q_t^k = \frac{S_t^k P_t^h}{P_t^k}.$$

S_t^k is the nominal exchange rate, whereby a fall in S^k implies an appreciation of the currency of country k against the base currency. $P_t^k = P(P_N^k, P_T)$ is the price index of the consumption basket in country k, and $P_t^h = P(P_N^h, P_T)$ is the corresponding price index in the base country. P_T denotes the price of the traded consumption good which is the same everywhere because I assume that shipping tradeables is costless. P_N^k are countries' prices of nontraded goods. If the traded good is set to be the numéraire good, this prices read as the relative prices of nontraded goods in country k. As these goods have to be consumed domestically, their prices will differ across countries which generates variation in the real exchange rate.

4.2.1 Optimal consumption allocation

In this economy with incomplete goods markets but frictionless trade in Arrow-Debreu securities, the optimal allocation of consumption equalizes the growth rate of marginal utility in all countries $k = 1 \dots K$, expressed in the same currency, and evaluated at common prices:

$$\frac{U_c\left(C_2^k(\omega)\right)}{U_c\left(C_1^k\right)} \frac{Q_2^k}{Q_1^k} = \frac{U_c\left(C_2(\omega)\right)}{U_c\left(C_1\right)} \tag{4.3}$$

where $\omega \varepsilon \Omega$ describes the realized history of states in the second period. This condition states that ex post, the common value of marginal utility growth will be the same everywhere. Following Obstfeld and Rogoff (2000), I call this the *international risk sharing condition*.

If the period utility function is of the constant relative risk aversion form as specified in equation (4.1) allows for an empirical test of the risk sharing condition (4.3), which therefore can be written as

$$\Delta c_{t+1}^k - \Delta c_{t+1}^h = \gamma(\Delta s_{t+1}^k + \Delta p_{t+1}^h - \Delta p_{t+1}^k). \tag{4.4}$$

Lowercase letters denote the logs of variables in levels, and Δ denotes first differences. Thus, full risk sharing implies that the difference between ex-post growth rates in consumption across countries should be a positive, linear function of the ex-post growth rate of the real exchange rate.

Starting with Backus and Smith (1993), the literature has thoroughly tested whether empirical measures for consumption growth, price growth and exchange rates behave as equation (4.4) predicts. In general, the literature finds little support for this risk-sharing condition. But Figure (4.1) of this paper, which shows relative price growth rates and relative consumption growth rates for Eurozone countries, points towards risk sharing: retail sales data of Eurozone countries reveal that countries with relatively low consumption growth tend to have increasing prices or appreciating real exchange rates.

4.2.2 Asset pricing

In our economy, households can trade in claims for tradeable output, and they can secure nontraded consumption by trading claims which are indexed to random nontradeable endowment, but which are payable in traded goods. The choice of the traded consumption good as the numéraire implies that in equilibrium, marginal utility growth of traded consumption will be equal for all countries — in a CCAPM framework, this marginal utility growth becomes the stochastic discount factor used to price all assets. With the consumption index assumed in equation (4.2), the stochastic discount factor is

$$M = \beta \frac{\left(\frac{\partial u(C_2)}{\partial C_T}\right)}{\left(\frac{\partial u(C_1)}{\partial C_T}\right)} = \beta \left(\frac{C_{T,2}}{C_{T,1}}\right)^{-\gamma} \left(\frac{1+\tau\left(\frac{C_{N,2}}{C_{T,2}}\right)^{\alpha}}{1+\tau\left(\frac{C_{N,1}}{C_{T,1}}\right)^{\alpha}}\right)^{(1-\alpha-\gamma)/(\alpha)} . \tag{4.5}$$

The assumption of non-separable preferences between traded and nontraded consumption has interesting implications for asset pricing: it is not only the co-variation of asset payouts with global, internationally traded consumption that determines an asset's price — see the first term of the discount factor —, but the co-variation of these payouts with the ratio of nontraded to traded consumption is relevant in addition. If investors are sufficiently risk-averse, which is described by the choice of α and γ, assets which promise high returns on average will pay low returns when global consumption is low, and when local consumption is particularly low in addition.

The price of a claim to country k's tradeable date 2 output is

$$V_{T,1}^{k} = E_1\left[MY_{T,2}^{k}\right]$$

where E_1 denotes expectations conditional on all information available at date 1. Claims to countries' nontradeable output are priced likewise, but in order to pay foreign asset holders, nontradeable payout bust be converted into tradeables locally at the local relative price:

$$V_{N,1}^{k} = E_1\left[MP_{N,2}^{k}Y_{N,2}^{k}\right]$$

4.2.3 Closed-form solution

To illustrate the risk-sharing mechanism in this model, I follow Hassan (2013) and derive a close-form solution by solving the Social Planner's problem around a deterministic steady state: the model can be solved approximately by log-linearizing the necessary first order conditions for optimality around the point in which the variance of date 2 endowments i zero. Details on the derivation of the results are given in the appendix. Lowercase letters denote the logs of variables in levels.

In equilibrium, countries consume all of their nontraded endowment, $c_N^k = y_N^k$. Equilibrium consumption of the traded good for any country $j \varepsilon \{K\}$ can be derived by using the economy's resource constraint together with the condition that marginal utility of traded consumption must be the same everywhere:

$$c_T^j = \frac{1}{K}\sum_{k=1}^{K} y_T^k + \left(\frac{\left(\gamma - \left(\frac{1}{1-\alpha}\right)^{-1}\right)(1-\tau)}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma} \right) \left(\frac{1}{K}\sum_{k=1}^{K} \left(y_N^k - y_N^j \right) \right). \tag{4.6}$$

Recall that $\left(\frac{1}{1-\alpha}\right)$ is the elasticity of substitution between traded and nontraded consumption goods in countries' utility function. If preferences are separable between traded and nontraded goods, that is if $\gamma = (1/(1-\alpha))^{-1}$, consumption of the traded good moves one-for-one with world supply: countries perfectly share risk of traded consumption. If countries are sufficiently risk averse however, $\gamma > (1/(1-\alpha))^{-1}$,[2] they strongly desire to smooth overall consumption over time. In this case, countries will share part of their nontraded consumption risk too by shipping traded goods: the second term on the right-hand-side of equation (4.6) shows that in this case, countries with below-average nontraded endowment at some point in time will consume above-average of the traded good. Hence, under the null of constrained-efficient risk sharing, this model predicts that countries' traded consumption can depend on domestic nontraded endowment growth, but not on domestic traded output growth different from average global growth. An important contribution is Lewis (1996) who tested this prediction and finds some support for it among countries with open asset markets.

If nominal exchange rates are fixed, the real exchange rate between any country k and the base country is given by the ratio of their relative prices. In the appendix, I show that the log of the real exchange rate increases in the log of the ratio of the two countries'

[2]See for example Hassan (2013) for a justification of this assumption. Technically, this condition implies that the relative price of a country's nontraded goods fall when its supply increases.

nontraded goods prices

$$q^k \equiv p^h - p^k \quad = \quad (1-\tau)(p_N^h - p_N^k). \tag{4.7}$$

Solving for the equilibrium relative prices leads to:

$$q^k \quad = \quad (1-\tau)\left(\frac{\left(\frac{1}{1-\alpha}\right)^{-1}\gamma}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right)\left(y_N^k - y_N^h\right) \tag{4.8}$$

The real exchange rate is a function of countries' relative endowment and consumption of the nontraded good. If agents are risk-averse and thus have a high elasticity of substitution between traded and nontraded consumption, $(\alpha/(1-\alpha))$, the real exchange rate will react less to differences in local endowments compared to the case with separable utility, $q^k = \gamma^{-1}(1-\tau)(y_N^k - y_N^h)$. Such a description of the real exchange rate may come closer to the behavior of empirical data, where price movements may be relatively small. To conclude, countries with relatively lower growth of nontraded endowment will have appreciating real exchange rates: risk sharing implies that purchasing power is transferred to countries in recession. To test this prediction, I will use versions of the following regression equation

$$\Delta q^k = \left(\Delta p_{N,t}^k - \Delta p_{N,t}^h\right) = \beta\left(\Delta y_{N,t}^k - \Delta y_{N,t}^h\right) + \nu_t^k \qquad \nu_t^k \sim \text{i.i.d}(0,\sigma^2)$$

Risk sharing predicts $\beta < 0$.

4.3 Literature

Backus and Smith (1993) and Kollmann (1995) have pointed out the monotone relationship between countries' consumption ratios and real exchange rates that versions of the complete-markets model with segmented goods markets predict. However, both contributions find little empirical support for this crisp prediction: Backus and Smith (1993) find that moments of quarterly relative consumption growth rates and real exchange rates are basically unrelated in a sample of OECD countries over 1971-1990, and Kollmann (1995) discovers that quarterly and annual (historical) logged consumption data and bilateral real exchange rates of seven major industrial countries are neither cointegrated, nor is there any close relationship between the growth rates of these variables. However, he shows that empirical tests cannot reject that real exchange rates are monotone in relative consumption growth rates in expectations, which is consistent with a model whit trade in risk-free bonds only.

The literature has dubbed the observation that relative consumption growth rates and relative prices are not positively related, but unrelated or even negatively related in many data samples, the "Backus-Smith puzzle" or the "consumption-real-exchange-rate puzzle". Numerous contributions take this as a stylized fact and develop richer models that can rationalize the observed behavior of consumption and exchange rates.[3] But there is also a number of recent contributions that chose an empirical approach to explain the Backus-Smith puzzle as it stands. Thereby, an effective approach has been to zoom in on risk sharing between countries with fixed versus floating nominal exchange rates, and on risk sharing across countries versus risk sharing among regions of the same country. Hess and Shin (2010) and Hadzi-Vaskov (2008) decompose real exchange rate fluctuations into goods price growth rates and growth rates of the nominal exchange rate and attribute the main source of the Backus-Smith puzzle to the behavior of the nominal exchange rate: Both studies conclude that among OECD countries, inflation differentials behave in line with theory, while nominal exchange rate fluctuations don't — since these latter are much more volatile than inflation differentials,[4] they determine real exchange rate movements and thus lie at the source of the Backus-Smith puzzle. Hess and Shin also show that the puzzle is less pertinent among countries with small nominal exchange rate fluctuations. Further, Hadzi-Vaskov (2008) finds that the Backus-Smith puzzle disappears among Eurozone countries after the introduction of the common currency, and, using retail sales data, Hess and Shin (2010) find support for exchange rate consumption risk sharing among US states which use a common currency too. Complementing these insights, a large literature on nominal exchange rate pass-through finds that retail prices often are sticky in the importer's currency so that even prices of highly traded goods do not satisfy the law of one price because they violate it at the border already (see for example Campa and Goldberg (2005)). Devereux and Hnatkovska (2014) have a thorough look at whether country borders alone, or country borders in combination with nominal exchange rate fluctuations lie at the source of the consumption-real-exchange-rate puzzle. Using regional consumption and price data for the US, Canada, Germany, Spain, and Japan, Devereux and Hnatkovska confirm the results reported above and find that nomi-

[3]For a list of references, see Hadzi-Vaskov (2008) on page 5, or the footnote on page 2 of Devereux and Hnatkovska (2014).

[4]Burstein and Gopinath (2014) name the observation that nominal exchange rates are volatile relative to prices a "stylized fact on the relation between international prices and real exchange rates".

nal exchange rate fluctuations are an important source of the puzzle, but they find other "border effects" too: possibly due to a common language, common institutions, greater trade linkages and factor mobility, regions within countries share more risk by relative price fluctuations than regions of different countries, even if the nominal exchange rate is held constant, and the distance between any two regions is controlled for. For countries having floating nominal exchange rates, Hoffmann and Suter (2013) develop an asset-pricing interpretation of the significant, model-inconsistent behavior of the exchange rate regarding consumption risk sharing: country portfolios with high consumption growth appreciate in expectation because this compensates risk averse investors for likely losses during global downturns. However, a study that finds no exchange rate risk sharing neither among countries having floating nominal exchange rates, nor within the Eurozone, is Devereux et al. (2012). Using professionals' forecasts, this authors argue that such a relationship even fails in expectations.

The complete markets model outlined in Section (4.2) predicts that relative inflation rates will shift purchasing power to countries with low income and, because of goods markets frictions, low consumption. But what if financial markets are incomplete? Intuitively, there could be a number of households in each country that do not attempt to insure consumption by trading assets but just consume their income every period (hand-to-mouth consumers). To them, relative prices don't matter. To test how robust empirical exchange-rate-consumption-risk-sharing results are to such an assumption, several authors have used countries' relative income growth rates together with real exchange rate changes (and other variables) to explain consumption growth differentials. The three studies cited above for example unanimously find that risk sharing results are not unaffected, but robust when controlling for relative income growth. Similarly, Hoffmann (2008) adapts the empirical risk-sharing model of Asdrubali et al. (1996) and Sorensen and Yosha (1998) to explicitly allow for goods market incompleteness. In this model, countries share more risk if their consumption growth responds less to short-term idiosyncratic income fluctuations.[5] Hoffmann finds that beside quantity flows — incomes from credit markets and capital markets —, relative price movements importantly equalize the value of consumption in a sample of 22 industrialized countries over 1973-2000,

[5] The complete markets model without any trade frictions predicts that consumption growth rates should be equal across countries. Cochrane (1991), or Mace (1991), or Townsend (1994) argued that rather testing for the significance of international consumption growth correlations, a more robust test for consumption risk sharing is to test whether individuals' consumption growth is independent of idiosyncratic income fluctuations. Following this insight, Asdrubali et al. (1996) decompose the variance of GDP into its accounting components which allows to quantify how much of countries' output fluctuations are buffered by cross-border income flows from capital and credit, and by fiscal insurance mechanisms.

as well as between regions in Australia, Canada, Germany, and Italy.

Richer countries have higher price levels. This “Penn-Effect” is a stylized fact in international economics and has been rationalized by Samuelson and Balassa who attributed it to higher productivity in the traded goods sector leading to higher nontraded goods prices, in particular, higher wages. This is another important aspect regarding the relationship between relative prices and countries’ wealth. For the Eurozone, several papers document such an effect,[6] which needs consideration in this paper: if fast growing countries have higher nontraded goods price inflation, and if income growth spills over into consumption growth, either because consumption risk sharing is incomplete as discussed above, or because consumers adjust consumption to permanently higher income levels, countries having high consumption growth should have *high* inflation. This effect would work against the hypothesis that this paper tests, which is that countries with higher consumption growth should have *lower* inflation. Against the background that productivity differentials are large within the Eurozone, the negative co-movement of relative consumption and relative prices I document in this paper provides even stronger evidence for the consumption real exchange rate correlation hypothesis inside the Eurozone.

Another, related topic for the Eurozone is the evolution of wages and house prices across countries — nontraded goods prices — and their apparent decoupling from macroeconomic fundamentals. De Grauwe (2012), for example, summarizes that over 2000 to 2008/09, excessively increasing unit labor costs have deteriorated the competitive positions of the so-called PIIGS which have accumulated large current account deficits (Portugal, Ireland, Italy, Greece, and Spain). Germany in contrast has improved its competitive position and runs current account surpluses.[7] To correct these imbalances, the PIIGS-countries are forced to engineer an “internal devaluation”, so that since about 2009, wages have been falling substantially in Ireland, Greece, and Spain, and — to a lesser extent however — in Portugal and Italy. This is taking place together with austerity measures which likely leads to a period of falling prices together with falling consumption. Again, such an effect works against the hypothesis of this paper which is

[6]Berka and Devereux (2013) for example find that relative GDP per capita is an important determinant of the real exchange rate not just in the aggregate, but also at the level of individual goods, and Berka et al. (2012) document that inside the Eurozone, countries with higher productivity of labor in the traded sector have higher nontraded prices, whereas such a relationship only holds only weakly between countries having floating nominal exchange rates. Lane and Honohan (2003) find that national output gaps help to explain inflation differentials in Europe, and Crucini et al. (2005) use microlevel data and find that PPP holds quite well in Europe, when prices are adjusted for GDP per capita.

[7]For a concise summary of countries’ economic position within the Eurozone, see for example the European Commission’s Quarterly Report on the Euro Area http://ec.europa.eu/economy_finance/publications/qr_euro_area/index_en.htm

that falling relative prices would go along with *increasing* relative consumption.

The baseline of this selective literature review is that real exchange rates between trading partners with a common currency tend to move as the international macroeconomic model predicts, whereas for partners having floating nominal exchange rates, the consumption real exchange rate correlation hypothesis is violated. Further, the Penn-Effect and the internal devaluation process, which is taking place in the deficit countries of the Eurozone, describe a positive co-movement of relative inflation and relative consumption growth. Against this background, the finding of this paper that aspects of relative price movements within the Eurozone contribute to exchange rate consumption risk sharing gains in importance.

4.4 Prices of traded and nontraded consumption

The price of a typical good little Joe pays for — say a hamburger at a takeaway — is a combination of both, prices for traded components of the burger and prices for its nontraded components: while the price for ketchup might predominantly be determined by global supply and demand, the rental costs for the takeaway stand accrue very locally and depend on local market conditions. Hence, the classical dichotomy of traded and nontraded goods might hardly be observable at the individual goods level. Accepting this constraint, it should be possible to construct sub-indexes of CPI's for goods of which one assumes that they have larger nontraded shares, and of goods that rather satisfy properties of traded goods, and it should then hold true that changes in relative prices of (baskets of) goods with presumably larger nontraded shares are the main drivers of the variance of the overall real exchange rate. In the existing literature however, such exercises do not yield clear-cut results: first and foremost, Engel (1999) finds no support for a different role for aggregated traded and nontraded goods prices in determining US real exchange rate fluctuations. In contrast, Berka et al. (2012) find support for the traded-nontraded goods model for the real exchange rate among countries of the Eurozone. These two studies side by side suggest that it could again be the behavior of nominal exchange rates that does not conform with the model. On the other hand, it might be useful to zoom in on highly disaggregated retail sales data to detect the classical dichotomy as Berka and Devereux (2010) or Crucini and Landry (2012) show. Starting from these insights — a common currency and disaggregated data help to find support for the traded-nontraded model for the real exchange rate, which nevertheless will be difficult to detect at the level of final goods — I continue to present the data I use in this study to test the traded-nontraded-goods-model for the exchange rate and the exchange rate consumption correlation hypothesis in the Eurozone. As is common in the literature, I will approximate consumption expenditures by retail sales data.

4.4.1 The data

All data is sourced from the Eurostat online database,[8] and it spans the period from January 2001 to December 2015. The sample includes data for Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Portugal, and Spain.[9] Growth rates — inflation rates and consumption growth — are calculated between each month and the same month of the previous year. This is a most simple way to control for seasonal effects.

The first panel includes consumption price indexes (CPI's) for goods categories aggregated at different levels. This dataset is used to explore whether the traded-nontraded goods model for the exchange rate finds empirical support: is it possible to find plausible price indexes for "traded" and "nontraded" goods whereby the "nontraded" goods prices contribute more to aggregate real exchange rate fluctuations? Monthly harmonized indexes of consumer prices (HIPC) (prc_hicp_midx) are available for individual countries, as well as for key country-groups of which the Monetary Union Index of Consumer Prices is used to measure the base economy's inflation, Δp^h. This index is a weighted average of countries' inflation whereby countries are included according to the evolution of the Eurozone. Eurostat makes available price indexes for around one hundred sub-indexes for different goods and services, as well as for special aggregates; this study uses a selection of both of these index types. In addition, relative item weights for all indexes are published once a year (prc_hicp_inw): the composition of the consumption baskets differ across countries and time.

The second panel includes retail sales indexes extracted from the Short-Term Business Statistics (STS). The STS provides short-term indicators for final domestic demand which can be used to approximate consumption growth of different goods categories and sub-categories. The STS gives information on economic activities according to the *Statistical Classification of Economic Activities in the European Community* (NACE) Rev.2, whereof division G47 is explored in this paper. Inflation rates corresponding to

[8]The European Commission's statistical office, http://ec.europa.eu/eurostat/de/data/database

[9]Not included in the sample are countries that adopted the euro only recently: Cyprus in 2008, Slovenia in 2007, Slovakia in 2009, Malta in 2008, Latvia in 2014, Lithuania in 2015, and Estonia in 2011. Further excluded from the sample is Luxembourg for its quite special industrial structure.

the sales indexes are obtained by the difference in the growth rate of total turnover- and volume indexes, because the database does not provide price indexes directly. Eventually, the empirical test of the exchange rate consumption risk sharing hypothesis bases on monthly calendar-adjusted data. Ideally, one would want to use the same dataset to test both, the traded-nontraded goods model for the exchange rate and the exchange rate consumption risk sharing hypothesis. Unfortunately, for the retail trade index, no item weights are available, and it is more difficult do define “traded” and “nontraded” goods than in the HIPC dataset. This makes it difficult to use the STS data to explore a variance decomposition of the real exchange rate, but it is suitable for testing risk sharing.

4.5 Real exchange rate fluctuations and consumer prices

To start, recall the definition of the real exchange rate between country k and a base economy h, $Q^k = P^h/P^k$, and the optimal aggregate price index (C.8) which is a geometric weighted average of the price of single goods $i\varepsilon\{I\}$, $P = \left(\sum_{i=1}^{I} \tau_i^{\varepsilon} P_i^{1-\varepsilon}\right)^{\frac{1}{1-\varepsilon}}$ with $\varepsilon = \frac{1}{1-\alpha}$. A log-linearized version of this price index (a first order approximation around the point with equal goods prices P_i) is given by $p = \sum_{i=1}^{I} \tau_i p_i$. Any aggregate real exchange rate can then be written as the sum of changes in law of one price (LOP) deviations or real exchange rates for single goods $i\varepsilon\{I\}$, $q_i^k \equiv p_i^h - p_i^k$,

$$q_t^k = \sum_{i=1}^{I} \tau_i q_{i,t}^k$$

Take the covariance of the variables on each side with respect to q_t^k and divide all terms by the variance of q_t^k to obtain

$$1 = \frac{cov\left(q_t^k, q_t^k\right)}{var\left(q_t^k\right)} = \sum_{i=1}^{I} \tau_i \frac{cov\left(q_{it}^k, q_t^k\right)}{var\left(q_t^k\right)} = \sum_{i=1}^{I} \tau_i \beta_i^k.$$

This variance decomposition of the real exchange can be aggregated to the two-goods traded-nontraded case:

$$\begin{aligned} q_t^k &= \tau q_{T,t}^k + (1-\tau) q_{N,t}^k \\ 1 &= \tau \beta_T^k + (1-\tau)\beta_N^k \end{aligned}$$

Under the null that the law of one price holds for traded goods, up to constant price deviations due to for example differences in transport costs, $\beta_T^k = 0$ and $\beta_N^k = (1-\tau)^{-1}$.

4.5.1 Empirical results

Given country-specific fluctuations in endowment, segmented goods markets effect adjustments of the real exchange rates among countries: in the model, the real exchange rate is a function of the prices of nontraded goods only. Starting from the variance decomposition of the real exchange rate above, does the data support these model assumptions and implications? Are the prices of goods for which markets probably are more segmented more important for the variance of the aggregate real exchange rate?

To answer these questions, the subsequent empirical analysis estimates the following regression for the panel of the "old" Eurozone countries:

$$\begin{aligned} \Delta q_{i,t}^k &= \alpha^k + \beta_i \Delta q_t^k + \delta_t + \varepsilon_{i,t}^k \\ q_{i,t}^k &= p_{i,t}^k - p_{i,t}^{\text{EMU}}. \end{aligned} \tag{4.9}$$

Real appreciation between country k and the Eurozone, $\Delta q_{i,t}^k$, is measured by the difference in the growth rates of a selection of HICP sub-indexes which presumably differ with respect to "tradability"; the aggregate real exchange rate corresponds to differences in the overall consumption price index, $\Delta q_t^k = \Delta \text{cpi}_t^k - \Delta \text{cpi}_t^{\text{EMU}}$. Table (4.1) presents the regression results.

To illustrate the variance decomposition, consider the HICP indexes for *goods* and *services*: I find that $\beta_{\text{goods}} = 0.9926$ and $\beta_{\text{serv}} = 1.0014$. Knowing the relative weight of these two goods categories in the overall CPI, $\tau_{\text{goods}} = 0.5816$ and $\tau_{\text{services}} = 0.4184$,[10] goods (services) explain roughly 58% (42%) of the variance of aggregate real exchange rates. Common sense suggests that markets for services are likely to be more segmented internationally than goods markets. In accordance with this guess, $\beta_{\text{serv}} > 1$ indicates that services contribute more than their expenditure share to the variability of the aggregate real exchange rate. Under the null of the model, and if traded and nontraded goods components are different from one another, but the same for all goods, β- estimates above one indicate goods with nontraded shares higher than those of the aggregate CPI. This just holds true for *services*. Particularly high β- estimates result for *rentals for housing* ($\beta = 1.42$), *hairdressing* ($\beta = 1.43$), *hospital services* ($\beta = 1.12$), or the *operation of personal transport equipment* ($\beta = 1.2$): these are all goods categories commonly characterized as "nontraded", and the analysis supports this assessment. In contrast,

[10]These weights are time-series averages over the weights of the two sub-indexes in the aggregate Eurozone index. The database provides these weights for each country separately, whereby weights are adjusted in January each year. But for the analysis in this section, it suffices to consider a broad estimate of these weights.

low β-estimates result for *industrial goods* ($\beta = 0.94$), *financial services* ($\beta = 0.8$), *communication services* ($\beta = 0.47$), *medical products* ($\beta = 0.42$), *electrical appliances* ($\beta = 0.83$), or the *purchase of vehicles* ($\beta = 0.87$) which are goods that we would characterize as tradeable. Going into more detail, the estimates support that processed food ($\beta = 1.13$) has a larger nontraded share than unprocessed food ($\beta = 0.99$), which "makes sense". The only puzzling result is found for energy ($\beta = 1.4$). Commonly, commodities are characterized as tradeables, but this high estimate for *energy* indicates a high importance of energy prices changes for national price inflation. This classification of goods is in line with results reported by De Gregorio et al. (1994) and Piton (2016) who classify goods as tradeable if at least 10% of total production is traded internationally. It also corresponds broadly to Engel (1999)'s disaggregation of OECD sectoral CPI data into tradeable and nontradeable subindexes. To summarize, the analysis here broadly supports the idea that real exchange rates are driven by prices of goods traded in rather segmented markets. This sets the stage for the empirical analysis of the exchange rate consumption risk sharing hypothesis in the next section.

4.6 Exchange rate consumption correlation

This section describes the results obtained from regressing relative price growth rates on relative consumption growth rates,

$$\Delta c_{i,t}^{k} - \Delta c_{i,t}^{EMU} \quad = \quad \delta^{k} + \beta \left(\Delta p_{i,t}^{k} - \Delta p_{i,t}^{EMU} \right) + \varepsilon_{i,t}^{k}.$$

By equation (4.8), the model predicts that countries with relatively low growth of nontraded endowment or consumption should have relatively high inflation and thus appreciating real exchange rates, $\beta < 0$. This relationship is stronger if consumers are more risk-averse and prefer substituting nontraded for traded consumption within periods to smooth consumption over time. But deriving assumptions on consumer's degree of risk aversion is beyond the scope of this paper. On the other hand, the results reported in section (4.5), results from the literature, and "common sense" allow to guess whether nontraded shares of various goods are large or small. Without loss of generality, assume for the moment that the traded-nontraded dichotomy holds, and that each single good is a composition of these two components. Abstracting from preference shocks, β-estimates in the above equation should be more negative for goods with a larger nontraded share. In what follows, I use annual growth rates of monthly retail sales indexes to test these predictions. Since relative weights of sub-indexes in higher aggregates are not available, I restrict the analysis on comparing quantities and deflators of the same level of aggregation.

Table (4.2) shows β- estimates and R^2 statistics for *total retail sales* as a measure for monthly consumption growth.[11] Apparently, changes in relative prices support consumption risk sharing since many slope estimates are negative and significantly different from zero. The panel estimates for the two sub-samples, one over 2001 to 2007, and the other over 2008 to 2015, are $\beta = -0.63$ and $\beta = -0.66$ respectively: a fall in a country's relative growth rate of retail sales of 1% goes along with an appreciation of the real exchange rate of about 0.6%. Referencing Crucini and Landry (2012), retail sales contain a nontraded share of 50% and more. Hence, under the null of the model, a one percent fall of the relative growth rate of the nontraded component of retail sales increases relative nontraded inflation by 1.2%. This provides strong support for exchange rate consumption risk sharing (and could further unveil risk-averse consumers).

The division of the sample into two subsamples, a "pre-crisis sample" and a "crisis sample", confirms further patterns documented elsewhere for the EMU. In the aftermath of the global financial crisis and the European sovereign debt crisis, Ireland saw a rapid internal devaluation: relative prices fell during the recession. The retail sales data unveil this fact: while exchange-rate risk sharing is found for Ireland over 2001 to 2007, $\beta^{IRE} = -1.23$, this estimate turns positive after 2008. Greece is the only country for which aggregate retail sales data never supports the exchange rate risk sharing hypothesis.

The intercept estimates are higher in the pre-crisis sample than in the post 2008 sample. This finds correspondence in the time-fixed effects from the panel specification which are higher and more significant over the first half of the sample, see Figure (4.2). Hence, the old Eurozone countries considered here have had relatively high retail sales growth rates over the first eight years of the euro relative to the extended Eurozone (the Eurozone retail sales index is a weighted average over 18 Eurozone countries). This has changed in 2008. In particular, Greece, Ireland, and Spain, and also Portugal, have had quite high sales growth prior to the crisis, but suffer from large drops thereafter. In contrast, Germany, France, and Austria have seen high average relative growth rates since 2008.

Tables (4.3), (4.4), and (4.5) present results for the complete sample over 2001 to 2015 for various sub-indexes of retail sales. First, Table (4.3) calls for an interpretation regarding nontradeable shares of different goods categories. The first index encompasses *sales via mail order houses or via internet*, a distribution channel that probably involves

[11] Total retail sales are given by the division G47 index included in the Short-Term Business Statistics. The classification is according to the *Statistical Classification of Economic Activities in the European Community* (NACE), Rev. 2.

few marketing services. This view is supported by the many insignificant β-estimates, and by the very low R^2 statistics: as for traded goods in the model, there is no significant relationship between relative quantities and relative prices. Quite in contrast, relative growth rates of retail sales of *health products* covary negatively with relative inflation rates, and R^2 statistics tend to be high — health products are likely to contain large non-traded shares. More ambiguous is the interpretation of the results found for the third index, which is *automotive fuel*. While fuel is the epitome of a traded good, slope coefficients are negative and large, and R^2 statistics are high, which is what one would expect for nontraded goods. This in accordance with the surprising result of section (4.9) where energy prices are found to be important drivers of real exchange rate adjustments. As regards the co-movement of fuel prices and quantities sold, a possible explanation is that consumers are highly price sensitive with respect to fuel. Alternatively, fuel could be interpreted as an intermediate good that is used to produce "personal mobility" which indeed is rather a not traded consumption good. With this latter interpretation, mobility prices would behave as expected for a nontraded good.

In Table (4.4), changes in prices and quantities of *non-food products sales* provide strong support for risk sharing as well. Here, the panel specification suggest that the index including *cultural and recreation goods* has a larger nontraded share than the index comprising *clothing*, but for single countries, evidence is mixed. Eventually, Table (4.5) presents results obtained from different retail sales indexes for *food products*: an overall index, an index that includes *sales in specialized stores* such as butcher's and bakeries, and an index that includes *sales in nonspecialized stores*, that is, in supermarkets. One would expect that food sold in specialized stores contains a larger nontraded share, but the regression analysis does not support such an interpretation: estimates are even more negative for supermarkets than for specialized stores. Maybe that people who buy in specialized stores are less price-sensitive?

To conclude, exchange rate consumption risk sharing that a model with goods markets frictions implies finds correspondence in Eurozone consumption price indexes and retail sales data. This is remarkable since it is difficult to measure frictions in goods trade in these data — they do not allow for a sharp distinction between "traded" and "nontraded" goods.

4.7 Focus on the cross-section

The focus so far has been on the time-series dimension of exchange rate risk sharing: whenever a country has below-average consumption growth, its real exchange rate tends to appreciate. But how do relative consumption and relative prices arrange in all countries at a given point in time? If today, one country suffers from a drop in consumption, and another does not, is it true that the real exchange rate between these two countries appreciates for the suffering country? The panel estimates of Tables (4.2) - (4.5) already confirm this hypothesis. In this section, a portfolio analysis allows to control for relative consumption growth rates which produces even sharper predictions on risk sharing.

4.7.1 Portfolios

Portfolios are built by sorting each month all countries on consumption growth. Then, from low to high growth, always two (three) countries build one portfolio. Hence, the first portfolio always contains the two countries with the lowest consumption growth rates, and the fifth portfolio always contains the countries with the highest consumption growth rates, and obviously, the composition of portfolios can change each month. This procedure allows for a focus on relative price movements between portfolios with fixed characteristics: portfolios are characterized by their cross-sectional rank of consumption growth. In asset pricing studies, it is common to price asset portfolios instead of single asset's return, the probably most prominent example are the Fama and French (1989) "size" and "book-to-market-ratio" equity portfolios.[12] Building portfolios of assets with similar characteristics averages out measurement errors and other noise in the data and thus allows for a sharp view on whether particular properties of assets predict returns. Moreover, portfolio formation is a most simple way to allow single assets to change characteristics over time and with this their exposure to the pricing factors of the model. Clearly, portfolios of only two countries formed here hardly average out noise in the data, but it makes possible to analyze the time-series behavior of the real exchange rate of "synthesized countries with constant characteristics", that is, of country portfolios with constantly high or low consumption growth.

[12] Fama and French (1989) sort equities on "size" and "book-to-market ratios" into portfolios and find that small firms with high book-to-market ratios pay high returns on average. Another example for portfolios is Lustig and Verdelhan (2007) who show that portfolios with high interest rate currencies systematically pay high returns.

4.7.2 Portfolio consumption growth and real appreciation

Consumption growth and corresponding prices are again approximated by the monthly retail-sales indexes introduced in Sections (4.4) and (4.6). Figures (4.3) and (4.4) present the portfolio exchange rate consumption risk sharing results, which are quickly summarized: the association of relative inflation rates with relative sales growth rates is more negative for sales indexes of which we suppose to contain a larger nontraded share. While the slope coefficient for the *total retail sales index* is $\beta = -0.0706$, it is $\beta = -0.1646$ for *retail sales of health articles* the prices of which presumably reflect a large nontraded services component: the negative association between the consumption of health products and their price is more than twice as large as it is for overall sales. On the other hand, the slope coefficient for *retail sales via mail order houses or via the internet* is the only estimate that is not significantly different from zero, as expected for a traded good. Interestingly, and in contrast to the results reported in section (4.6), a larger nontraded component in *food sales in specialized stores* than in *food sales in supermarkets* now is apparent: I find $\beta_{\text{supermarket}} = -0.0730$ and $\beta_{\text{spec. stores}} = -0.1438$. Thus, controlling for relative consumption growth helps to unveil that at each point in time, and for various proxies of consumption growth, countries with relatively low growth tend to have appreciating real exchange rates. Moreover, the traded-nontraded model for the real exchange rate finds support since such a relationship is more distinct for consumption of which we suppose that it has a larger nontraded share.

4.7.3 An asset pricing perspective

The above section has shown that a monotone association between portfolio consumption growth and expected appreciation is very distinct: expected appreciation increases from high- to low growth portfolios, whereby the difference between portfolio's appreciation is larger for goods that presumably have larger nontraded shares. This makes curious to know whether portfolio's appreciation is systematically related to the European business cycle. From an asset pricing perspective, it would be interesting to explore whether the high expected return of low consumption growth portfolios comes at certain costs. In the consumption based asset pricing model (CCAPM), these costs finds correspondence in the covariance of returns with marginal utility of investors. In the model outlined in section (4.2), marginal utility growth of investors, which is the stochastic discount factor in the CCAPM framework, depends on both, global and local consumption growth. Piazzesi et al. (2007) approximate local, nontraded consumption by housing services and find that this version of the CCAPM can outperform the standard CCAPM. Hassan (2013) presents an application to currency returns. He observes that large economies systematically pay low returns and argues that in a model-world with nonseparable utility, low nontraded endowment in a large economy increases demand for traded consumption globally which makes claims to large countries nontraded consumption a good hedge against global risk.

In the economy described in this paper, investors can trade claims indexed to any country's nontraded consumption, but which are payable in traded consumption. Think of such claims as inflation-indexed bonds as many governments issue. A holder of such a bond profits whenever inflation in the issuer country is higher than inflation in the country in which he wishes to consume. In the data described in this paper, this holds true for countries with low consumption growth.

If the discount factor is linear in traded and nontraded consumption,[13] Table (4.6) presents least square estimation results from regressing time series of portfolio real appreciation on the two Eurozone risk factors "traded" and "nontraded" consumption growth:

$$\Delta p_t^j - \Delta p_t^{EMU} \quad = \quad a^j + \beta_T^j \Delta c_{T,t}^{EMU} + \beta_N^j \Delta c_{N,t}^{EMU} + \varepsilon_t, \qquad j = 1 \ldots 5$$

Nontraded consumption growth Δc_N^{EMU} is approximated by *sales in specialized stores*. Turning to the estimation results, the β_N^j coefficients are monotonically falling in portfolios' consumption growth rank: β_N^j is highest for the low-growth portfolio and lowest for the high-growth portfolio. Figures (4.5) and (4.6) visualize this monotone relationship, and the CCAPM-interpretation is as follows: because they perform especially bad when overall nontraded consumption is low and possibly very unevenly distributed, low growth portfolios pay a positive expected return which compensates asset holders for the risk they expose themselves to when buying claims to low c-growth portfolio's consumption.

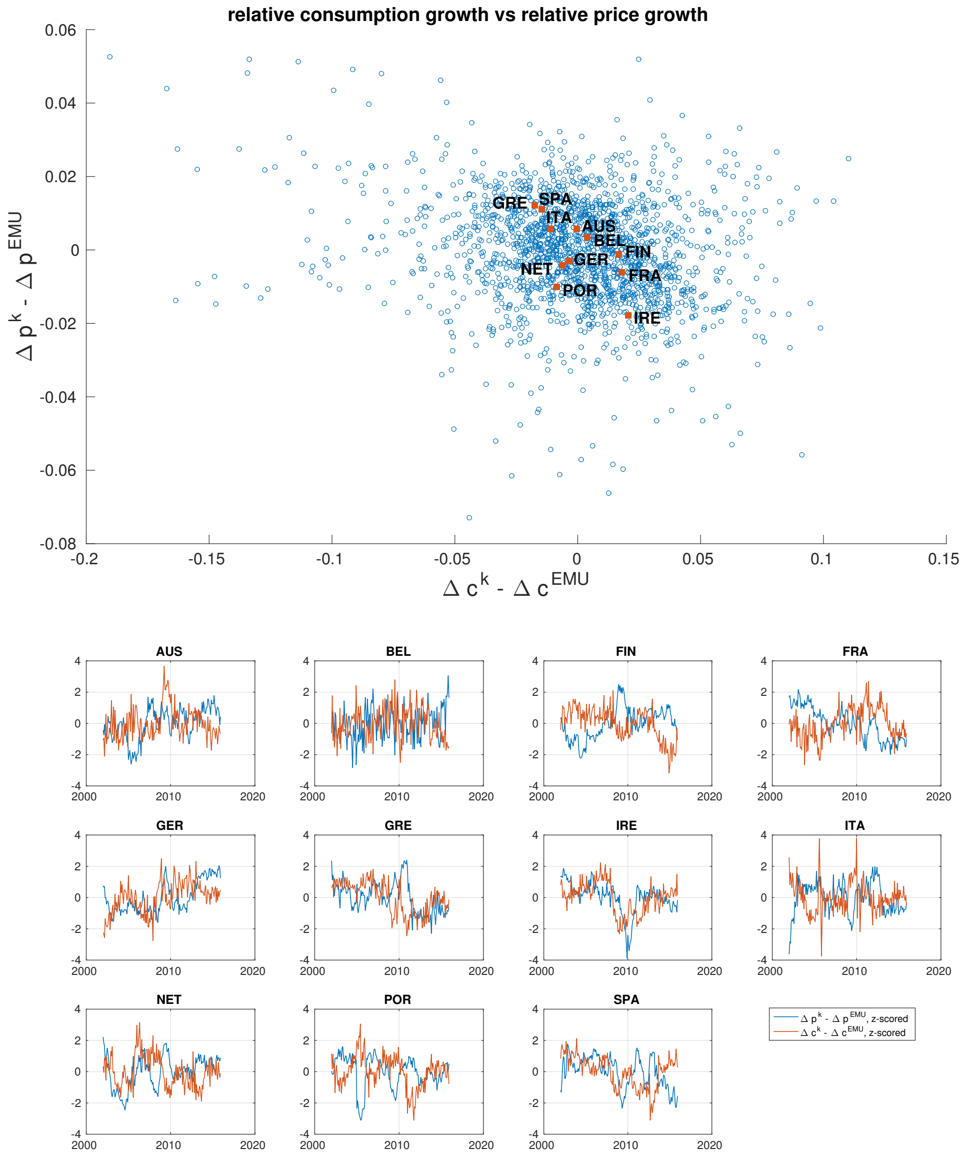
The lower panel of Table (4.6) reveals that the nontraded risk factor Δc_N^{EMU} is priced, i.e., that the relationship between the five β_N^j-coefficient estimates and expected exchange rate returns is significant. Global nontraded endowment growth explains cross-sectional differences in expected exchange rate returns.

[13] The analysis of whether CCAPM-type covariance risk can explain returns from inflation differentials should be taken with a grain of salt, because there is no conditioning information in the model (consumption growth is unpredictable ex ante such that investing in low growth countries is not an investable strategy), and because results are not very robust. Further, calibrating investor's discount factor given by equation (4.5) is beyond the scope of this paper. Rather, I assume that the discount factor is linear in traded and nontraded consumption growth, which is in the spirit of the exposition in the textbook by Cochrane (2005), chapters 12 and 13. This said, the discussion here could pioneer future research.

4.8 Conclusion

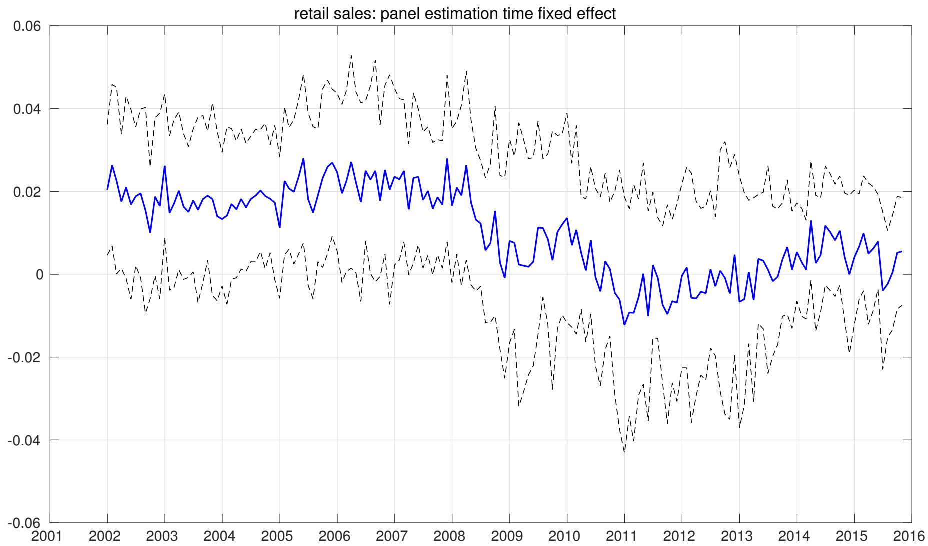
The joint behavior of consumption of various goods and of relative consumer price inflation not only supports the traded-nontraded goods model for the real exchange rate, but also confirms the exchange rate consumption correlation hypothesis between the initial Eurozone countries: prices of goods with higher nontraded shares explain larger shares of the variance of the aggregate real exchange rate between individual countries and the Eurozone, and countries with relatively high inflation have relatively low consumption growth, as measured by monthly retail sales data. The predictive power of consumption growth rates for real appreciation becomes particularly clear for consumption growth sorted country portfolios: portfolios with a higher (lower) cross-sectional rank of consumption growth depreciate (appreciate) by more. The interplay of relative consumption and relative prices is not that puzzling!

Figure 4.1: Relative price growth and relative consumption growth within EMU countries



The scatterplot shows relative growth rates of $k = 1 \ldots K$ countries' consumption $(\Delta c_t^k - \Delta c_t^{EMU})$ against relative growth rates of corresponding prices $(\Delta p_t^k - \Delta p_t^{EMU})$. The blue circles indicate every country-time observation of relative consumption growth and relative inflation, and the red squares indicate the time-series averages of the two variables for each country. Consumption and consumer prices are approximated by the Eurostat Short-Term Business Statistics index for *total retail sales* (NACE Rev.2 division index G47). The data is at monthly frequency, growth rates are measured between each month and the same month of the previous year. Figures for the whole euro area, denoted "EMU", correspond to a weighted average over 18 Eurozone countries. The data covers the period from January 2001 to December 2015. The lower plot shows time series of countries' relative retail sales (consumption) growth and relative inflation rates; the series shown are centered to have mean zero and variance one.

Figure 4.2: Risk sharing time fixed effect

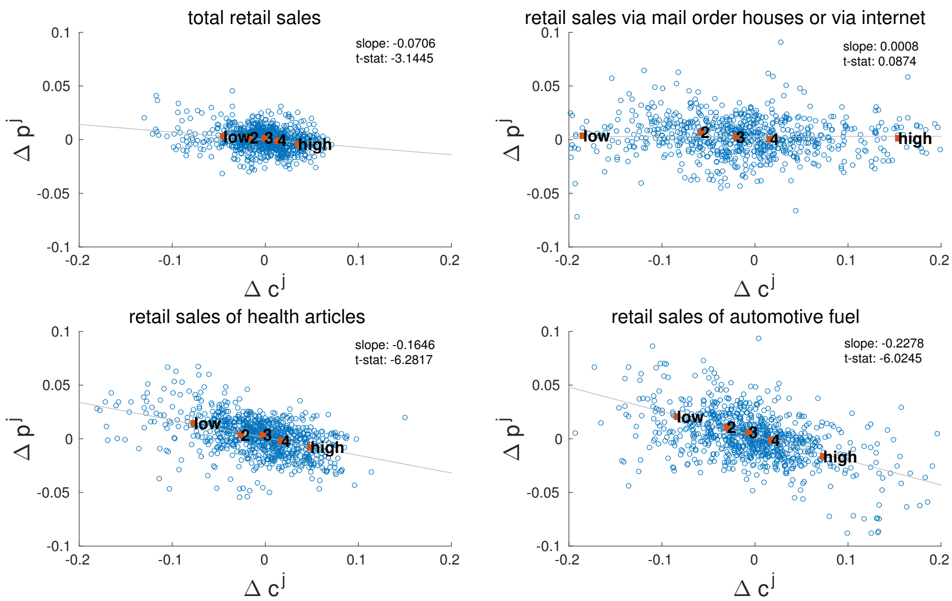


This figures shows estimates for the time fixed effect τ_t plus/minus two standard errors from the following panel regression

$$\left(\Delta c_t^k - \Delta c_t^{EMU}\right) = \beta\left(\Delta p_t^k - \Delta p_t^{EMU}\right) + \delta^k + \tau_t + \varepsilon_t.$$

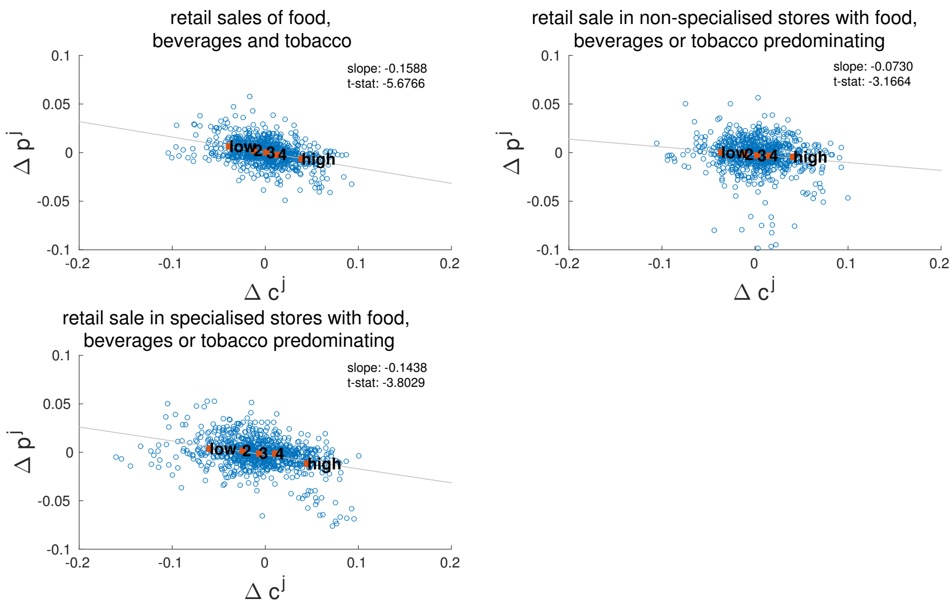
Δc is approximated by the growth rate of the total retail sales index (NACE Rev. 2 classification G47), and Δp is the inflation of the corresponding price index. The data is at monthly frequency and growth rates are measured between each month and the same month of the previous year. The countries included in the sample are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain. HAC-consistent standard errors are calculated following Newey and West (1987) and Newey and West (1994).

Figure 4.3: Exchange rate consumption risk sharing at the portfolio level



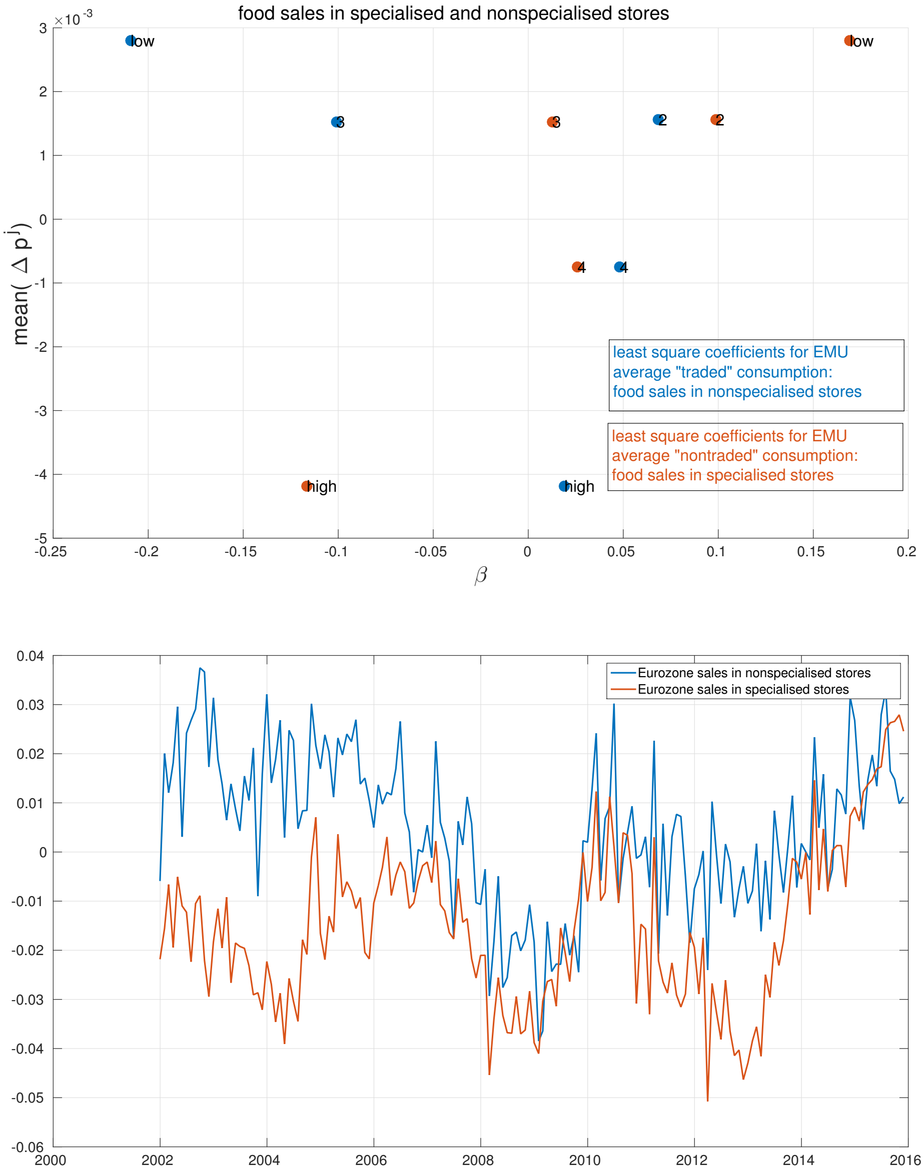
The scatterplots plot relative consumption growth rates against relative inflation rates. Each observed pair of relative consumption growth and relative price growth is calculated as a portfolio average. The $j = 1 \dots 5$ portfolios are build by sorting each month all countries on consumption growth. Then, from low to high growth, always two countries build one portfolio. The composition of portfolios changes each month. Prior to portfolio formation, relative consumption growth rates and relative inflation rates are measured as the difference between country k's growth rate and the Eurozone average growth rate. The least squares line are fitted to the blue circles which show all monthly combinations of portfolios' relative consumption growth rates and relative inflation rates. The red squares show portfolio time series average consumption growth and inflation: each month, those countries that are selected into the high relative consumption growth portfolio are expected to have lowest relative inflation. Countries included in the sample are Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain, and the data reaches from January 2001 to December 2015. Growth rates are annual. *Total retail sales* corresponds to the NACE Rev.2 classification division index G47, *retail sales via mail order houses or via internet* is the class index G4791, *dispensing chemist; retail sale of medical and orthopaedic goods, cosmetic and toilet articles in specialised stores* is a combined index G47_NF_HLTH, *retail sale of automotive fuel in specialised stores* is the group index G473.

Figure 4.4: Exchange rate consumption risk sharing at the portfolio level, cont'd



The scatterplots plot relative portfolio average consumption growth rates against relative portfolio average inflation rates. Portfolios and portfolio average consumption and inflation are build as described in the notes of Figure (4.3). *Retail sales of food, beverage and tobacco* correspond to the combined NACE Rev.2 division index G47_FOOD, *retail sale in non-specialised stores with food, beverages or tobacco predominating* is the NACE Rev.2 class index G4711, and *retail sale in specialised stores with food, beverages or tobacco predominating* is the NACE Rev.2 group index G472.

Figure 4.5: Loading on risk factors vs expected returns, food sales data

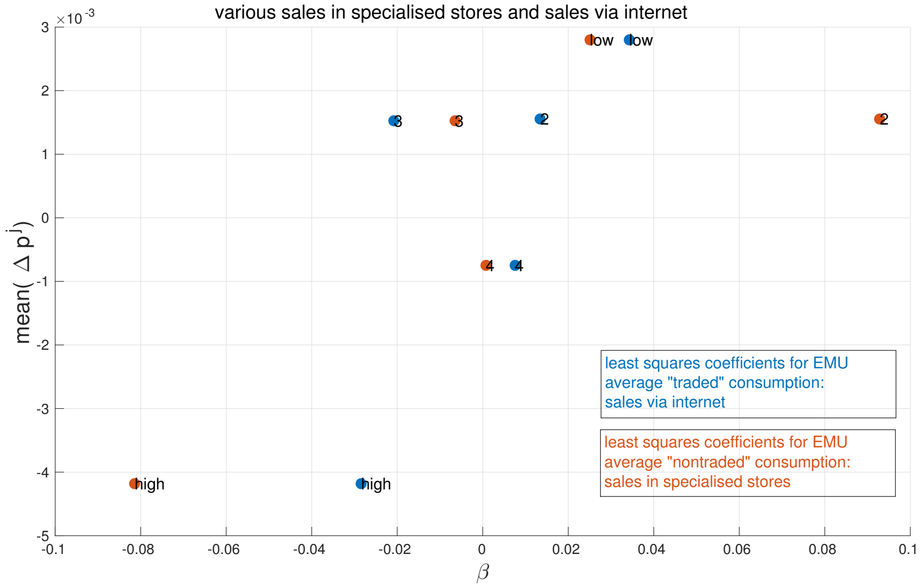


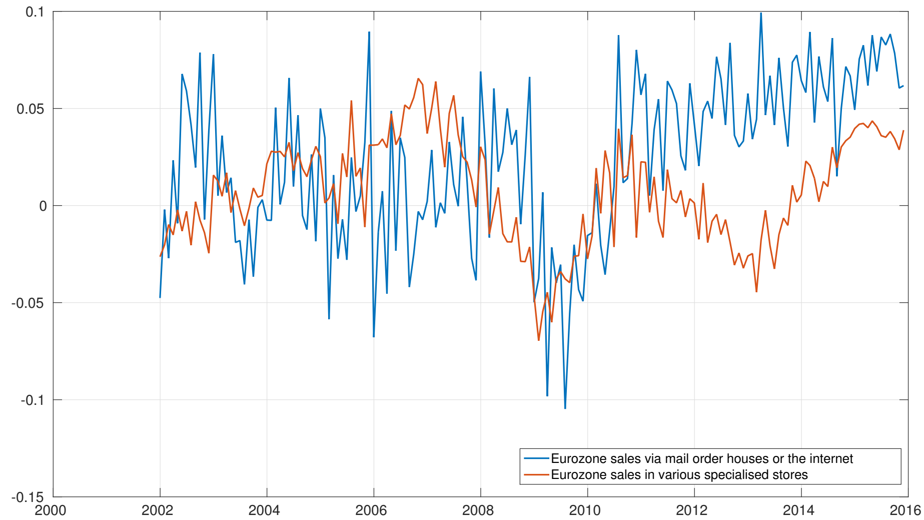
The upper figure plots least square coefficient estimates against time-series average relative portfolio inflation rates. Portfolios are built by sorting countries on total consumption growth as described in the notes of Figure (4.3).

$$\Delta p_t^j - \Delta p_t^{EMU} \quad = \quad \alpha + \beta_1^j \Delta c_{T,t}^{EMU} + \beta_2^j \Delta c_{N,t}^{EMU} + \varepsilon_t.$$

The blue (red) dots indicate β_1^j (β_2^j). On the vertical axis, the plot shows time series averages of portfolio's appreciation against the EMU, mean$\Delta p^j = \frac{1}{T}\sum_{t=1}^{T}\left(\Delta p_t^j - \Delta p_t^{EMU}\right)$. Inflation is measured by the price index for *total retail sales* (NACE Rev.2 division index G47). The pricing factor Δc_T^{EMU} corresponds to the growth rate of volume estimates of *retail sales in non-specialised stores with food, beverages or tobacco predominating* (NACE Rev.2 class index G4711) and the factor Δc_N^{EMU} is the growth rate of volume estimates of *retail sales in specialised stores with food, beverages or tobacco predominating* (NACE Rev.2 group index G472). The lower figure plots the time series graphs of the two pricing factors. The data is monthly and reaches from 2001 to 2015, growth rates are measured between each month and the same month of the previous year. The countries included in the sample are the "old" Eurozone countries listed in the main text.

Figure 4.6: Loading loading on risk factors vs expected returns, differing distribution channels





The upper figure plots least square coefficient estimates against time-series average relative portfolio inflation rates. Portfolios are built by sorting countries on total consumption growth as described in the notes of Figure (4.3).

$$\Delta p_t^j - \Delta p_t^{EMU} \quad = \quad \alpha + \beta_1^j \Delta c_{T,t}^{EMU} + \beta_2^j \Delta c_{N,t}^{EMU} + \varepsilon_t.$$

The blue (red) dots indicate β_1^j (β_2^j). On the vertical axis, the plot shows time series averages of portfolio's appreciation against the EMU, $\text{mean}\Delta p^j = \frac{1}{T}\sum_{t=1}^{T}\left(\Delta p_t^j - \Delta p_t^{EMU}\right)$. Inflation is measured by the price index for *total retail sales* (NACE Rev.2 division index G47). The pricing factor Δc_T^{EMU} corresponds to the growth rate of volume estimates of *retail sales via mail order houses or via internet* (NACE Rev.2 class index G4791) and the factor Δc_N^{EMU} is the growth rate of volume estimates of *retail sale of information and communication equipment; other household equipment (except textiles); cultural and recreation goods, etc. in specialised stores* (compiled Short-Term Business Statistics Index G47-NF-OTH). The data is monthly and reaches from 2001 to 2015, growth rates are measured between each month and the same month of the previous year. The countries included in the sample are the "old" Eurozone countries listed in the main text.

Table 4.1: Variance decomposition of goods-level real exchange rates

HIPC Index: tradables	β_i	$\overline{\tau}_i^{\text{EMU}}$	**HIPC Index: nontradables**	β_i	$\overline{\tau}_i^{\text{EMU}}$
Goods (overall index excluding services)	0.9926				
	(0.0378)	0.5816			
Food including alcohol and tobacco	1.0843				
	(0.0831)	0.1943			
Processed food including alcohol and tobacco	1.1325				
	(0.1052)	0.1193			
Unprocessed food	0.9906				
	(0.1252)	0.0750			
Seasonal food	0.9828				
	(0.1997)	0.0380			
Industrial goods	0.9441				
	(0.0798)	0.3873			
Energy	1.4069				
	(0.3713)	0.0961			
			Services (overall index excluding goods)	1.0014	
				(0.0524)	0.4184
Financial services n.e.c.	0.8036		Services related to housing	1.1905	
	(0.4873)	0.0059		(0.1554)	0.1022
Services related to communication	0.4667		Domestic services and household services	0.7358	
	(0.1711)	0.0306		(0.1694)	0.0089
Services related to package holidays and accommodation	1.0255				
	(0.1688)	0.0327			
			Health	1.0423	
				(0.1304)	0.0418
Medical products, appliances and equipment	0.4239		Out-patient services	0.9705	
	(0.3658)	0.0183		(0.1732)	0.0173
			Hospital services	1.1182	
				(0.3335)	0.0061
			Personal care	1.0046	
				(0.1046)	0.0279
Electrical appliances for personal care;	0.8300		Services related to recreation and personal care,	1.0025	
other appliances, articles and products for personal care	(0.1300)	0.0162	excluding package holidays and accommodation	(0.0708)	0.1149
			Hairdressing salons and personal grooming establishments	1.4347	
				(0.1425)	0.0117
Transport	0.9935				
	(0.1737)	0.1539			
Purchase of vehicles	0.8661		Operation of personal transport equipment	1.1819	
	(0.1480)	0.0440		(0.3390)	0.0877
Transport services	0.8826				
	(0.1463)	0.0222			
			miscellaneous		
			Restaurants and hotels	0.9917	
				(0.0684)	0.0936
			Actual rentals for housing	1.4197	
				(0.2641)	0.0614
			Administered prices	0.9533	0.1617
				(0.1296)	

The table presents panel coefficient estimates as well as HAC-consistent standard errors for

$$\Delta q_{i,t}^k = \alpha^k + \beta_i \Delta q_t^k + \delta_t + \varepsilon_{i,t}^k.$$

Δq_t^k denotes the change of the aggregate real exchange rate for country k against the Eurozone. It is measured by the growth rate of the deviation of country k's overall consumption price index from the Eurozone average index, $\Delta \text{cpi}_t^k - \Delta \text{cpi}_t^{\text{EMU}}$ extracted from Eurostat's monthly harmonized indexes of consumer prices (HIPC) (prc_hicp_midx). On the right-hand side of the regression equation, $\Delta q_{i,t}^k$ denotes country k's relative growth rate of the sub-index i of the CPI, $\Delta p_{i,t}^k - \Delta p_{i,t}^{\text{EMU}}$. The relative weight of the sub-index i in the overall CPI of country k at time t is denoted $\tau_{i,t}^k$ which is between zero and one, the overall CPI has weight $\tau_{CPI,t}^k = 1$. α^k and δ_t are a country- and a time-fixed effect respectively. Monthly growth rates are measured between each month and the same month of the previous year. The data reaches from January 2001 to December 2015. Countries included in the sample are the "old" Eurozone countries listed in the main text. Standard errors are corrected for heteroscedasticity and autocorrelation following Newey and West (1987) and Newey and West (1994).

Table 4.2: Risk sharing in retail sales

	2001(1)-2015(12)			2001(1)-2007(12)			2008(1)-2015(12)		
	β	δ	R^2	β	δ	R^2	β	δ	R^2
Panel	−0.2148			**−0.6268**			**−0.6575**		
	(−1.2349)		0.15	(−4.6776)		0.47	(−3.0633)		0.41
Austria	−0.2831	0.0013		**−0.7446**	**−0.0061**		**−1.3173**	**0.0188**	
	(−1.3808)	(0.5797)	0.02	(−3.3926)	(−3.4160)	0.18	(−3.5593)	(4.2838)	0.13
Belgium	**−0.7283**	**0.0063**		**−0.6556**	0.0007		−0.7886	0.0087	
	(−2.9236)	(2.1309)	0.06	(−2.4188)	(0.2168)	0.08	(−1.9454)	(1.9240)	0.06
Finland	**−0.9554**	**0.0155**		−0.1728	**0.0308**		−0.4931	0.0061	
	(−5.5300)	(4.9050)	0.27	(−0.8790)	(11.6801)	0.01	(−1.3723)	(1.0554)	0.04
France	**−0.6823**	**0.0138**		−0.4458	**0.0101**		0.5078	**0.0302**	
	(−2.6384)	(7.1681)	0.10	(−1.3761)	(5.1298)	0.03	(1.2537)	(9.4570)	0.03
Germany	**0.4338**	−0.0022		−0.5903	**−0.0215**		**−0.5860**	**0.0078**	
	(2.2524)	(−0.9738)	0.05	(−0.7414)	(−2.6946)	0.03	(−4.6835)	(4.7021)	0.17
Greece	0.3753	−0.0222		−0.2798	**0.0418**		−0.6082	**−0.0653**	
	(0.5154)	(−1.8920)	0.01	(−0.8804)	(5.4581)	0.01	(−1.4716)	(−6.8310)	0.05
Ireland	**0.8681**	**0.0361**		**−1.2307**	**0.0344**		0.4288	0.0145	
	(3.8913)	(6.0163)	0.13	(−3.8075)	(9.1925)	0.21	(1.3987)	(1.4566)	0.05
Italy	**−0.8899**	**−0.0062**		**−0.9686**	**−0.0070**		−0.7882	−0.0009	
	(−4.6234)	(−3.4005)	0.15	(−2.9358)	(−2.9253)	0.15	(1.7419)	(−0.0050)	0.14
Netherlands	−0.0467	**−0.0067**		**0.7352**	0.0074		**−0.5617**	**−0.0151**	
	(−0.2000)	(−1.9830)	0.00	(2.9729)	(1.5619)	0.18	(−2.2990)	(−6.5481)	0.07
Portugal	**−1.0667**	**−0.0192**		**−1.0787**	**−0.0076**		**−1.8008**	**−0.0421**	
	(−5.4793)	(−3.9669)	0.24	(−6.1425)	(−2.5070)	0.52	(−4.0523)	(−4.5881)	0.30
Spain	−0.4539	−0.0098		**−1.3881**	**0.0337**		**−2.3229**	**−0.0179**	
	(−0.9727)	(−1.6274)	0.02	(−4.0593)	(6.0162)	0.23	(−5.7478)	(−3.4004)	0.51

$$\left(\Delta c_t^k - \Delta c_t^{EMU}\right) = \beta\left(\Delta p_t^k - \Delta p_t^{EMU}\right) + \delta^k + \tau_t + \varepsilon_t$$

The table reports OLS estimates and HAC-consistent Newey and West (1987) and Newey and West (1994) t-statistics obtained from regressing the relative growth rate of a measure of countries' real consumption, $(\Delta c_t^k - \Delta c_t^{EMU})$, on the relative growth rate of a measure of countries' real consumption prices, $(\Delta p_t^k - \Delta p_t^{EMU})$, as well as an intercept δ (or country-fixed effects δ^k and time fixed effects τ_t in the panel specification). Consumption and consumer prices are extracted from the Eurostat short-term business statistics: consumption at current and constant prices is approximated by the working day adjusted index of turnover in retail trade, except motor vehicles and motorcycles (NACE Rev 2 statistics G47), and the growth rate of consumption prices corresponds to the difference in the growth rate of sales turnover at current and constant prices, as the database does not present price indexes for sales data directly. The data is at monthly frequency, and growth rates are measured between each month and the same month of the previous year. Figures for the whole Euro area, denoted "EMU", correspond to a weighted average over 18 Eurozone countries.

Table 4.3: Risk sharing in retail sales sub-indexes

	Retail sale via mail order houses or via Internet			Retail sale of automotive fuel in specialised stores			Dispensing chemist; retail sale of medical and orthopedic goods, cosmetic and toilet articles in specialised stores		
	β	δ	R^2	β	δ	R^2	β	δ	R^2
Panel	−0.3305			**−0.6876**			**−0.5134**		
	(−0.5572)		0.06	(−6.3054)		0.11	(−3.3557)		0.21
Austria	−0.0677	**−0.0250**		**−1.1798**	−0.0012		**−0.3969**	−0.0041	
	(−0.1481)	(−2.8506)	0.00	(−5.1074)	(−0.1343)	0.32	(−2.0689)	(−0.9922)	0.04
Belgium	−0.5120	−0.0071		**−1.1484**	**0.0163**		**−1.2895**	−0.0014	
	(−0.9009)	(−0.5638)	0.01	(−4.6828)	(2.0846)	0.24	(−3.9972)	(−0.2364)	0.09
Finland	**−1.0655**	0.0009		**−0.9203**	−0.0079		**−0.8232**	**0.0179**	
	(−2.0286)	(0.0690)	0.03	(−6.0474)	(−1.4891)	0.31	(−5.2704)	(3.9412)	0.33
France	0.7706	0.0067		**−1.4030**	**0.0136**		−0.1181	**0.0297**	
	(1.2110)	(1.3229)	0.01	(−3.8098)	(2.4249)	0.30	(−0.3606)	(5.2682)	0.00
Germany	−0.5111	−0.0026		**−0.9308**	**−0.0131**		0.0761	0.0018	
	(−0.9369)	(−0.5878)	0.01	(−4.2772)	(−2.1215)	0.29	(0.5844)	(0.9377)	0.00
Greece	−0.0256	−0.0380		**−0.2900**	**0.0040**		**1.0928**	**−0.0329**	
	(−0.0113)	(−0.5568)	0.00	(−2.2444)	(0.1862)	0.03	(2.8937)	(−3.5713)	0.16
Ireland				**−0.5550**	0.0060		**0.5411**	0.0091	
				(−2.9247)	(0.9181)	0.09	(3.5555)	(1.2792)	0.07
Italy	**−1.6436**	0.0110		**−0.8427**	0.0029		**−0.8838**	**−0.0179**	
	(−2.3676)	(0.7649)	0.02	(−5.8702)	(0.7418)	0.52	(−3.3242)	(−3.4456)	0.11
Netherlands	**−1.5887**	**0.0354**		**−0.4233**	−0.0027		−0.2599	−0.0056	
	(−2.3051)	(3.9545)	0.07	(−2.8850)	(−0.5513)	0.16	(−1.3760)	(−1.1844)	0.04
Portugal	**1.6751**	**−0.0493**		**−1.1275**	**−0.0215**		**−0.9119**	**−0.0332**	
	(5.2313)	(−4.0277)	0.13	(−11.6088)	(−2.5619)	0.49	(−4.3112)	(−4.5045)	0.35
Spain	1.2196	**−0.0583**		**−0.3678**	0.0055		**−1.2956**	0.0057	
	(1.2000)	(−2.6083)	0.03	(−2.1332)	(0.7930)	0.04	(−6.4952)	(0.9225)	0.50

$$\left(\Delta c_t^k - \Delta c_t^{EMU}\right) = \beta\left(\Delta p_t^k - \Delta p_t^{EMU}\right) + \delta^k + \tau_t + \varepsilon_t$$

The table reports OLS estimates and HAC-consistent Newey and West (1987) and Newey and West (1994) t-statistics obtained from regressing the relative growth rate of a measure of countries' real consumption, $(\Delta c_t^k - \Delta c_t^{EMU})$, on the relative growth rate of a measure of countries' real consumption prices, $(\Delta p_t^k - \Delta p_t^{EMU})$, as well as an intercept δ (or country-fixed effects δ^k and time fixed effects τ_t in the panel specification). Consumption and consumer prices are extracted from the Eurostat short-term business statistics. The growth rate of consumption prices corresponds to the difference in the growth rate of sales turnover at current and constant prices, as the database does not present price indexes for sales data directly. The data is at monthly frequency, and growth rates are measured between each month and the same month of the previous year. Figures for the whole Euro area, denoted "EMU", correspond to a weighted average over 18 Eurozone countries.

Table 4.4: Risk sharing in retail sales sub-indexes, cont'd

	Retail sale of non-food products (except fuel)			Retail sale of textiles, clothing, footwear and leather goods in specialised stores			Retail sale of information and communication equipment; other household equipment (except textiles); cultural and recreation goods, etc. in specialised stores		
	β	δ	R^2	β	δ	R^2	β	δ	R^2
Panel	−0.1636			**−0.3554**			**−0.7549**		
	(−0.9242)		0.17	(−2.6368)		0.06	(−6.3221)		0.24
Austria	**−0.5521**	−0.0013		**−0.8029**	0.0018		**−0.8316**	0.0046	
	(−3.6727)	(−0.4359)	0.08	(−4.6494)	(0.4979)	0.11	(−9.6966)	(1.1903)	0.24
Belgium	**−0.9812**	**0.0121**		−0.0955	**0.0241**		**−1.0099**	**0.0204**	
	(−5.4120)	(2.1352)	0.12	(−0.2558)	(2.6707)	0.00	(−8.4503)	(3.2848)	0.31
Finland	**−1.9975**	**0.0141**		**−0.7648**	**0.0144**		**−1.1857**	**0.0263**	
	(−7.3965)	(3.0665)	0.41	(−3.3759)	(2.3071)	0.09	(−5.9061)	(5.1164)	0.39
France	0.1785	**0.0308**		**−1.1446**	**0.0186**		**−0.3638**	**0.0322**	
	(0.7360)	(16.1759)	0.01	(−4.0495)	(5.7747)	0.14	(−2.1133)	(15.1294)	0.09
Germany	**0.9153**	−0.0037		−0.1852	−0.0021		−0.3973	−0.0069	
	(4.2007)	(−1.3242)	0.12	(−0.6998)	(−0.5549)	0.00	(−1.5316)	(−1.5180)	0.03
Greece	0.8467	**−0.0422**		−0.3022	−0.0222		−0.6028	−0.0168	
	(1.9220)	(−3.5239)	0.06	(−0.7600)	(−1.3556)	0.01	(−1.3656)	(−1.2422)	0.03
Ireland	**0.8854**	**0.0481**		0.2312	**0.0526**		0.4089	**0.0300**	
	(3.2391)	(4.5504)	0.14	(0.8552)	(4.0954)	0.01	(0.8830)	(2.1319)	0.02
Italy	−0.1154	**−0.0127**		**−1.2369**	**0.0000**		**−1.1512**	0.0024	
	(−0.3897)	(−3.7341)	0.00	(−5.8394)	(0.0134)	0.16	(−15.9146)	(0.6243)	0.58
Netherlands	0.0914	**−0.0108**		**−0.3816**	**−0.0096**		**−0.6486**	**−0.0179**	
	(0.3697)	(−2.3865)	0.00	(−2.1385)	(−2.3624)	0.04	(−1.9607)	(−3.0214)	0.05
Portugal	−0.4830	**−0.0250**		**−0.7666**	−0.0093		−0.8518	**−0.0322**	
	(−1.5428)	(−4.2688)	0.03	(−5.1598)	(−1.4196)	0.13	(−1.7685)	(−3.9236)	0.06
Spain	**−2.5259**	0.0042		**1.0781**	**−0.0162**		**−1.6436**	−0.0054	
	(−4.3631)	(0.5803)	0.25	(3.1517)	(−3.1470)	0.13	(−2.7541)	(−0.4992)	0.09

$$\left(\Delta c_t^k - \Delta c_t^{EMU}\right) = \beta\left(\Delta p_t^k - \Delta p_t^{EMU}\right) + \delta^k + \tau_t + \varepsilon_t$$

The table reports OLS estimates and HAC-consistent Newey and West (1987) and Newey and West (1994) t-statistics obtained from regressing the relative growth rate of a measure of countries' real consumption, $(\Delta c_t^k - \Delta c_t^{EMU})$, on the relative growth rate of a measure of countries' real consumption prices, $(\Delta p_t^k - \Delta p_t^{EMU})$, as well as an intercept δ (or country-fixed effects δ^k and time fixed effects τ_t in the panel specification). Consumption and consumer prices are extracted from the Eurostat short-term business statistics. The growth rate of consumption prices corresponds to the difference in the growth rate of sales turnover at current and constant prices, as the database does not present price indexes for sales data directly. The data is at monthly frequency, and growth rates are measured between each month and the same month of the previous year. Figures for the whole Euro area, denoted "EMU", correspond to a weighted average over 18 Eurozone countries.

Table 4.5: Risk sharing in retail sales sub-indexes, cont'd

	retail sales of food in specialized stores			retail sales of food in nonspecialized stores			Retail sale of food, beverages and tobacco		
	β	δ	R^2	β	δ	R^2	β	δ	R^2
Panel	**−0.4050**			**−0.4007**			**−0.4231**		
	(−4.4672)		0.17	(−2.8980)		0.1219	(−3.9658)		0.1360
Austria	**−0.5820**	0.0085		**−0.9012**	**0.0165**		**−0.7470**	**0.0132**	
	(−2.3410)	(1.5686)	0.09	(−6.0799)	(7.4501)	0.14	(−4.0652)	(5.2313)	0.11
Belgium	−0.4934	−0.0076		**−0.9313**	**0.0074**		**−0.8492**	0.0047	
	(−1.6161)	(−1.1743)	0.03	(−7.5674)	(2.6161)	0.26	(−10.7426)	(1.7838)	0.47
Finland	−0.3963	**0.0193**		−0.2400	**0.0133**		**−0.2217**	**0.0143**	
	(−3.9622)	(3.8989)	0.20	(−1.6444)	(3.7102)	0.04	(−2.0547)	(4.3686)	0.04
France	**−0.9295**	**0.0364**		**−1.2987**	**−0.0033**		**−1.2404**	0.0015	
	(−2.8197)	(11.1904)	0.17	(−3.5620)	(−0.8986)	0.18	(−3.2820)	(0.4143)	0.17
Germany	0.0075	**−0.0092**		−0.3210	**−0.0009**		**−0.2371**	−0.0008	
	(0.0252)	(−2.9850)	0.00	(−1.3660)	(−0.3153)	0.02	(−1.1597)	(−0.2781)	0.01
Greece	−0.4623	−0.0121		0.2513	−0.0002		−0.2098	−0.0028	
	(−1.1752)	(−1.1459)	0.02	(0.5036)	(−0.0155)	0.01	(−0.5134)	(−0.2655)	0.01
Ireland	**0.5813**	**0.0157**		**0.5675**	**0.0335**		**0.6494**	**0.0346**	
	(3.9247)	(3.2283)	0.08	(2.0399)	(5.2143)	0.05	(2.5840)	(5.7303)	0.08
Italy	**−0.8342**	**−0.0080**		0.0030	**−0.0109**		−0.2398	**−0.0102**	
	(−2.1286)	(−3.6939)	0.06	(0.0085)	(−3.2596)	0.00	(−0.7091)	(−3.4269)	0.00
Netherlands	**−0.7205**	**−0.0229**		−0.3368	**0.0080**		−0.2153	0.0034	
	(−3.0119)	(−7.5074)	0.15	(−1.9493)	(2.9050)	0.05	(−1.4797)	(1.5745)	0.03
Portugal	**−0.8714**	**−0.0414**		**−1.0640**	−0.0029		**−0.8689**	−0.0047	
	(−3.6928)	(−4.5083)	0.12	(−10.9095)	(−0.5720)	0.41	(−8.5775)	(−1.11851)	0.36
Spain	**−0.1996**	−0.0051		**0.4872**	**−0.0137**		0.2456	**−0.0135**	
	(−0.8315)	(−1.1795)	0.01	(2.9346)	(−3.6281)	0.06	(1.7017)	(−3.9038)	0.02

$$\left(\Delta c_t^k - \Delta c_t^{EMU}\right) = \beta\left(\Delta p_t^k - \Delta p_t^{EMU}\right) + \delta^k + \tau_t + \varepsilon_t$$

The table reports OLS estimates and HAC-consistent Newey and West (1987) and Newey and West (1994) t-statistics obtained from regressing the relative growth rate of a measure of countries' real consumption, $(\Delta c_t^k - \Delta c_t^{EMU})$, on the relative growth rate of a measure of countries' real consumption prices, $(\Delta p_t^k - \Delta p_t^{EMU})$, as well as an intercept δ (or country-fixed effects δ^k and time fixed effects τ_t in the panel specification). Consumption and consumer prices are extracted from the Eurostat short-term business statistics. The growth rate of consumption prices corresponds to the difference in the growth rate of sales turnover at current and constant prices, as the database does not present price indexes for sales data directly. The data is at monthly frequency, and growth rates are measured between each month and the same month of the previous year. Figures for the whole Euro area, denoted "EMU", correspond to a weighted average over 18 Eurozone countries.

Table 4.6: Does consumption growth price real exchange rates? – an attempt

Country-level time series estimation: $\Delta p_t^j - \Delta p_t^{EMU} = a^j + \beta_T^j \Delta c_{T,t}^{EMU} + \beta_N^j \Delta c_{N,t}^{EMU} + \varepsilon_t, \qquad j = 1\dots5$

	food sales in supermarkets (T) and spec. stores (N)				sales via internet (T) and specialised stores sales (N)			
	a^j	β_T^j	β_N^j	R^2	a^j	β_T^j	β_N^j	R^2
low Δc	0.0063	−0.2092	0.1692		0.0018	0.0342	0.0250	
	(2.6929)	(−3.0275)	(2.0258)	0.05	(1.0360)	(1.2369)	(0.8944)	0.01
port 2	−0.0014	−0.0008	0.0986		0.0006	0.0135	0.0929	
	(1.7999)	(1.1963)	1.6019	0.05	(0.6448)	(0.6924)	(3.7077)	0.07
port 3	0.0022	−0.1010	0.0126		0.0021	−0.0208	−0.0065	
	(1.6318)	(−1.9931)	0.2540	0.02	(1.9516)	(−1.2374)	(−0.1841)	−0.00
port 4	−0.0006	0.0482	0.0259		−0.0009	0.0075	0.0007	
	(−0.4852)	(0.7563)	0.5527	0.00	(−0.7781)	(0.4042)	(0.0217)	−0.01
high Δc	−0.0060	0.0191	−0.1166		−0.0029	−0.0285	−0.0814	
	(−4.0020)	(0.1993)	−1.5727	0.02	(−3.1565)	(−1.6102)	(−2.5943)	0.07

Cross-sectional estimation: $\frac{1}{T}\sum_{t=1}^{T}\left(\Delta p_t^j - \Delta p_t^{EMU}\right) = \beta_T^j \lambda_T + \beta_N^j \lambda_N + \alpha^j$

λ_T	λ_N	λ_T	λ_N
−0.0022	0.0198	0.0314	0.0252
(−0.3205)	(2.8555)	(0.7986)	(1.8628)

The table shows least squares estimates of time series a's and β's and factor prices λ obtained from applying the Fama-MacBeth procedure to price exchange rate returns using "traded" and "nontraded" Eurozone average consumption growth as pricing factors. T-statistics for the time-series estimates are corrected for heteroscedasticity and serial correlation followingNewey and West (1987) and Newey and West (1994). T-statistics for λ correct for the fact that $\hat{\beta}$'s are generated regressors following Shanken (1992). Test assets are the real exchange rates of $j = 1\dots5$ country portfolios. Portfolios are build by sorting each month all countries on consumption growth. Then, from low to high growth, always two countries build one portfolio. The composition of portfolios changes each month. Portfolio exchange rate returns (real appreciation against the Eurozone average, $\Delta p_t^j - \Delta p_t^{EMU}$) are measured by the price index for *total retail sales* (NACE Rev.2 division index G47) extracted from the Eurostat Short-Term Business Statistics. On the left, Δc_T^{EMU} corresponds to the growth rate of volume estimates of *retail sales in non-specialised stores with food, beverages or tobacco predominating* (NACE Rev.2 class index G4711) and the factor Δc_N^{EMU} is the growth rate of volume estimates of *retail sales in specialised stores with food, beverages or tobacco predominating* (NACE Rev.2 group index G472). On the right, the pricing factor Δc_T^{EMU} corresponds to the growth rate of volume estimates of *retail sales via mail order houses or via internet* (NACE Rev.2 class index G4791) and the factor Δc_N^{EMU} is the growth rate of volume estimates of *retail sale of information and communication equipment; other household equipment (except textiles); cultural and recreation goods, etc. in specialised stores* (compiled Short-Term Business Statistics Index G47-NF-OTH). The data is monthly and reaches from 2001 to 2015, growth rates are measured between each month and the same month of the previous year. The countries included in the sample are the "old" Eurozone countries listed in the main text.

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Appendix A

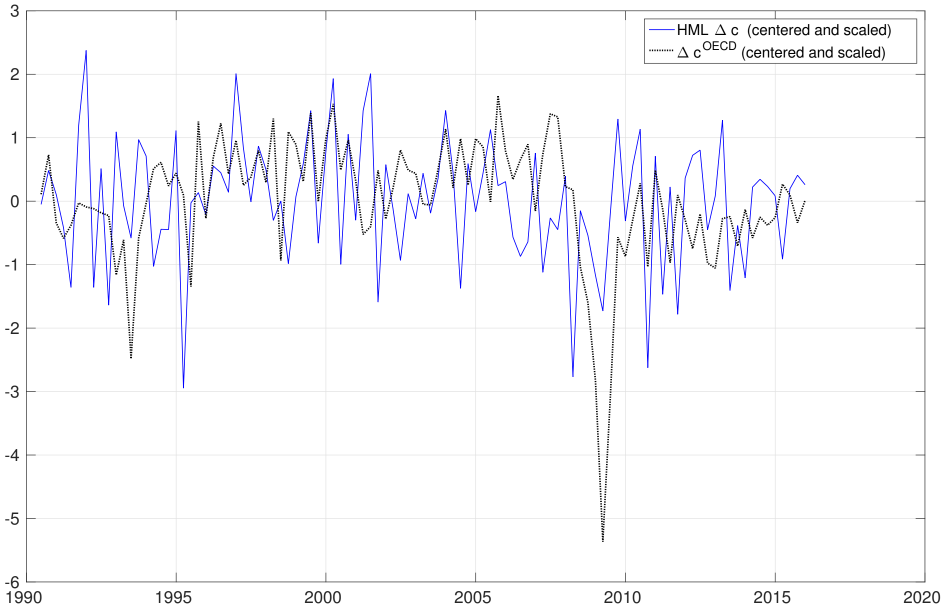
Systematic consumption risk in currency returns

A.1 Data

Quarterly consumption data is sourced from the OECD national accounts database. Consumption corresponds to "private final consumption expenditures", whereof seasonally adjusted quarterly growth rates compared to the same quarter of the previous year have been downloaded. Forward exchange rates correspond to 3 month forward rates provided by WM/Reuters and accessed via Datastream. Spot rates are downloaded via Datastream as well, but originate from various sources (WM/Reuters, MSCI, BOE). Quarterly values are constructed as averages over the last ten trading days of each quarter. For each country or currency respectively, data is included only if all, forward exchange rates, spot exchange rates, and consumption growth rates are available. Euro area countries are no longer included separately in the sample once they introduced the euro, but summarized in the "Euro area 17 countries" variable. The Menkhoff et al. (2012a) currency market volatility index is constructed from a broader currency data set. Otherwise, the data includes the following countries/currencies: Australia (AUD,1990Q1-2015Q4), Austria (ATS, 1990Q1-1999Q1), Belgium (BEF, 1990Q1-1999Q1), Canada (CAD, 1990Q1-2015Q4), Czech Republik (CRK, 1997Q1-2015Q4), Denmark (DKK, 1990Q1-2015Q4), Estonia (EEK, 2004Q2-2011Q1), France (FRF, 1990Q1-1999Q1), Germany (DEM, 1990Q1-1999Q1), Greece (GRD, 1997Q1-2001Q1), Hungary (HUF, 1998Q1-2015Q4), Iceland (ISK, 2004Q2-2015Q4), Ireland (IEP, 1990Q1-1999Q1), Italy (ITL, 1990Q1-1999Q1), Israel (ILS, 2004Q2-2015Q4), Japan (JPY, 1990Q1-2015Q4), Mexico (MXN, 1997Q1-2015Q4), Netherlands (NLG, 1990Q1-1999Q1), New Zealand (NZD, 1990Q1-2015Q4), Norway (NOK, 1990Q1-2015Q4), Poland (PLN, 1996Q4-2015Q4), Portugal (PTE, 1990Q1-1999Q1), South Korea (KRW, 2002Q2-2015Q4), Sweden (SEK, 1990Q1-2015Q4), Switzerland (CHF, 1990Q1-2015Q4), Spain (ESP, 1990Q1-1999Q1), United Kingdom (GBP, 1990Q1-2015Q4), United States (USD, 1990Q1-2015Q4), Euro area 17 countries (EUR, 1999Q1-2015Q4).

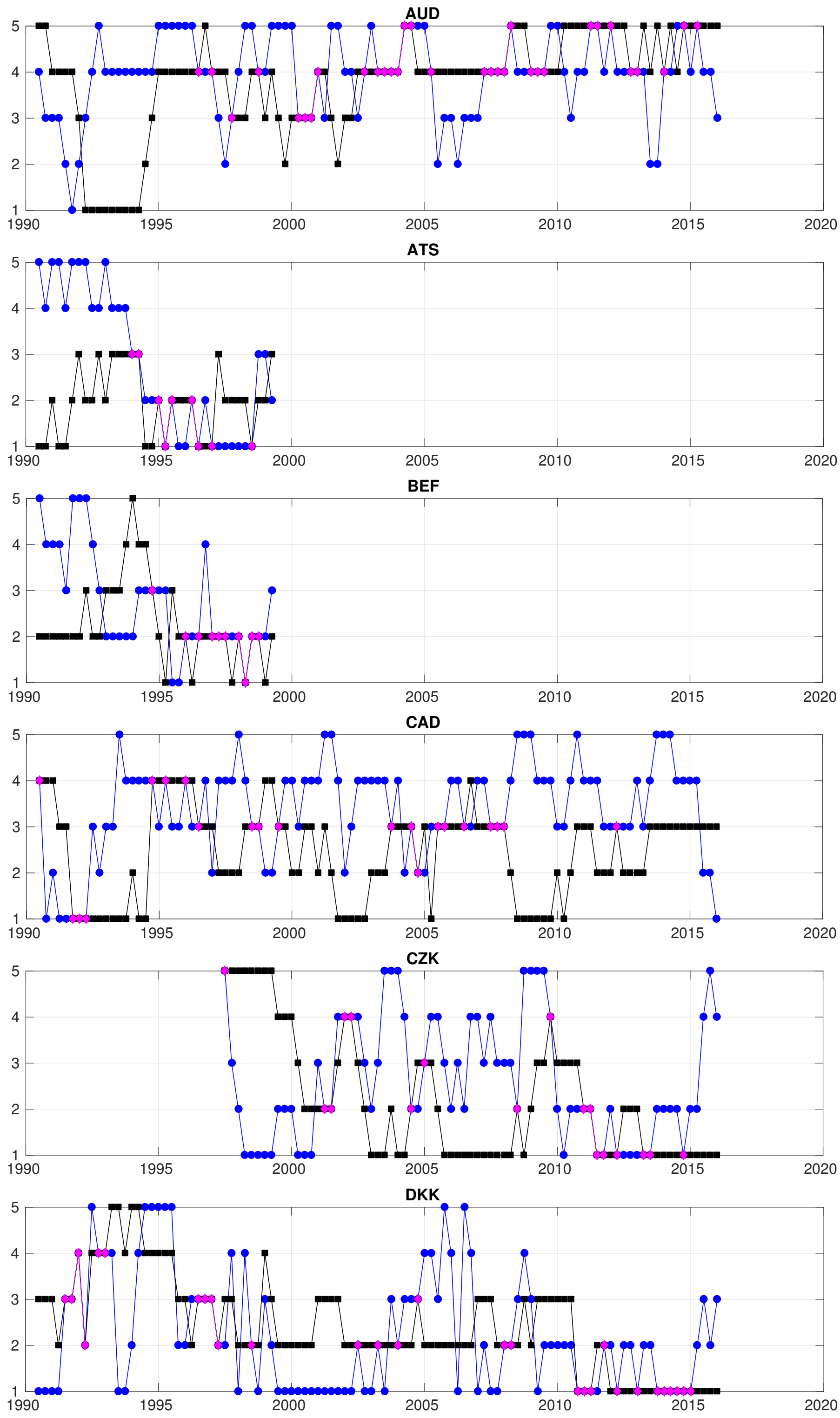
A.2 Figures

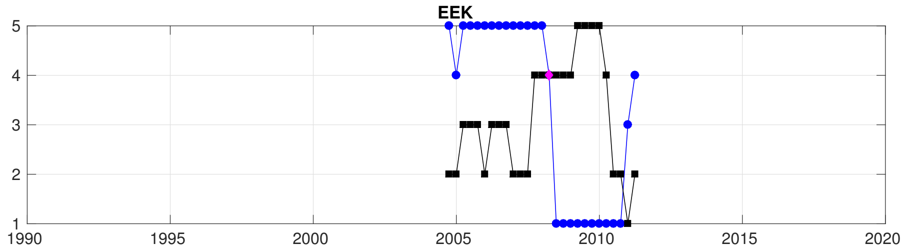
Figure A.1: $\text{HML}_{\Delta c}$ and sample average consumption growth



The blue solid line plots the consumption carry trade factor $\text{HML}_{\Delta c}$, and the black, dotted line plots the sample average consumption growth rate Δc^{OECD}. $\text{HML}_{\Delta c}$ corresponds to the cross-country average return a global investor obtains when she borrows in the currencies of countries which experienced low consumption growth over the last year and invests in currencies of countries that experienced a year of relatively high consumption growth. Δc^{OECD} corresponds to the equally weighted sample average of quarterly consumption growth rates. Both variables are centered to have mean zero and standardized to a variance of one. Both variables are constructed from quarterly data which encompasses the OECD sample specified in the main text.

Figure A.2: Comparison of consumption sorted and forward discount sorted portfolios

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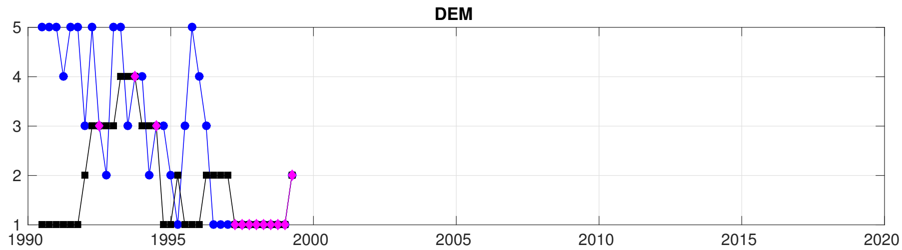
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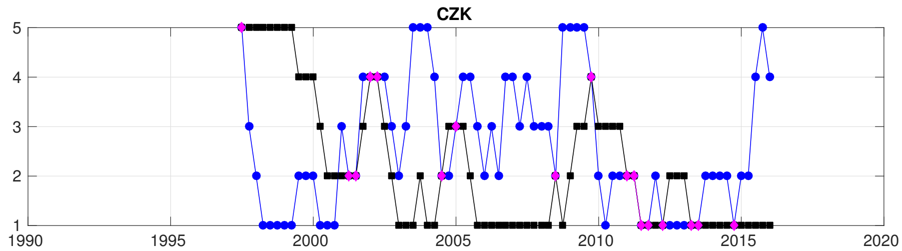
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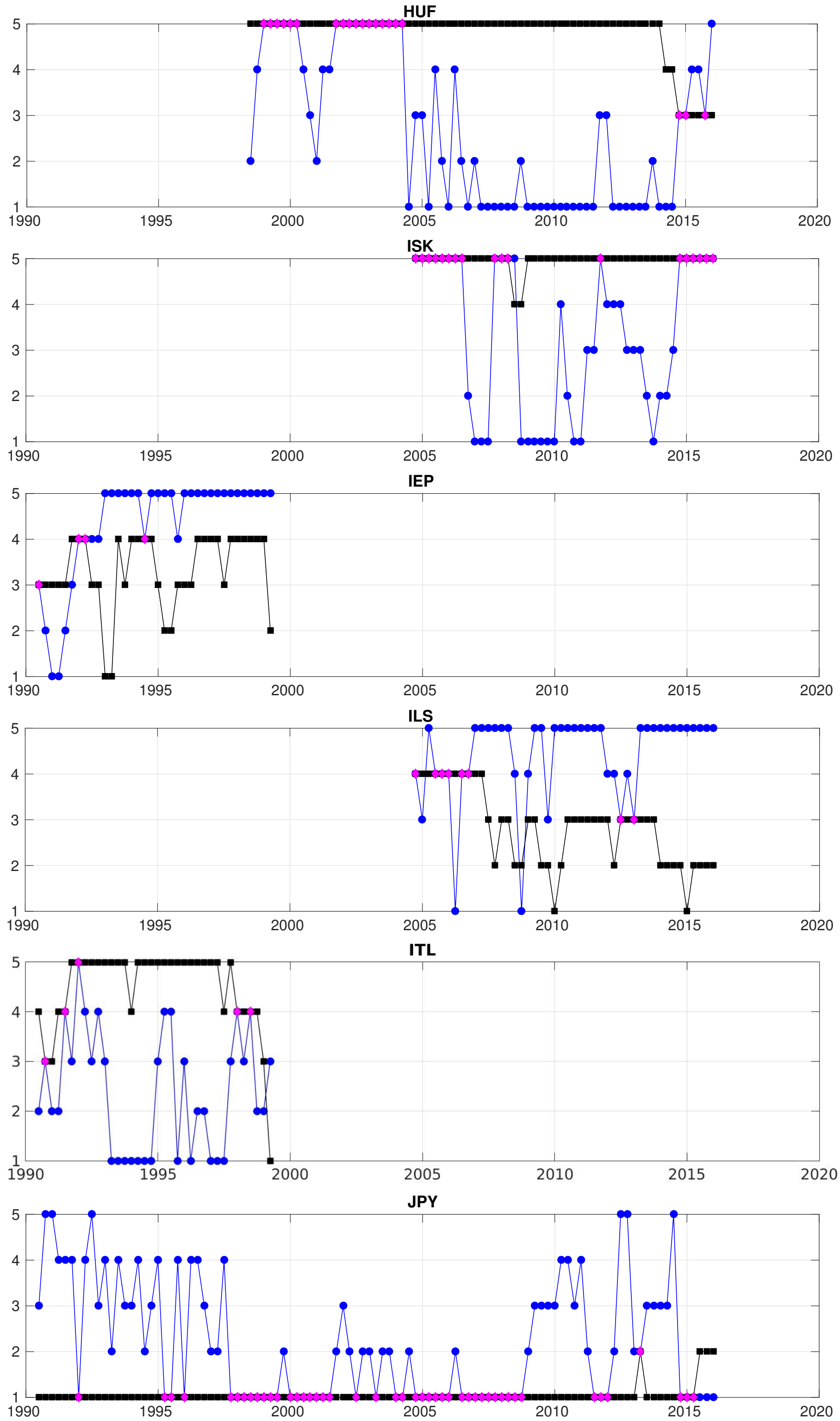
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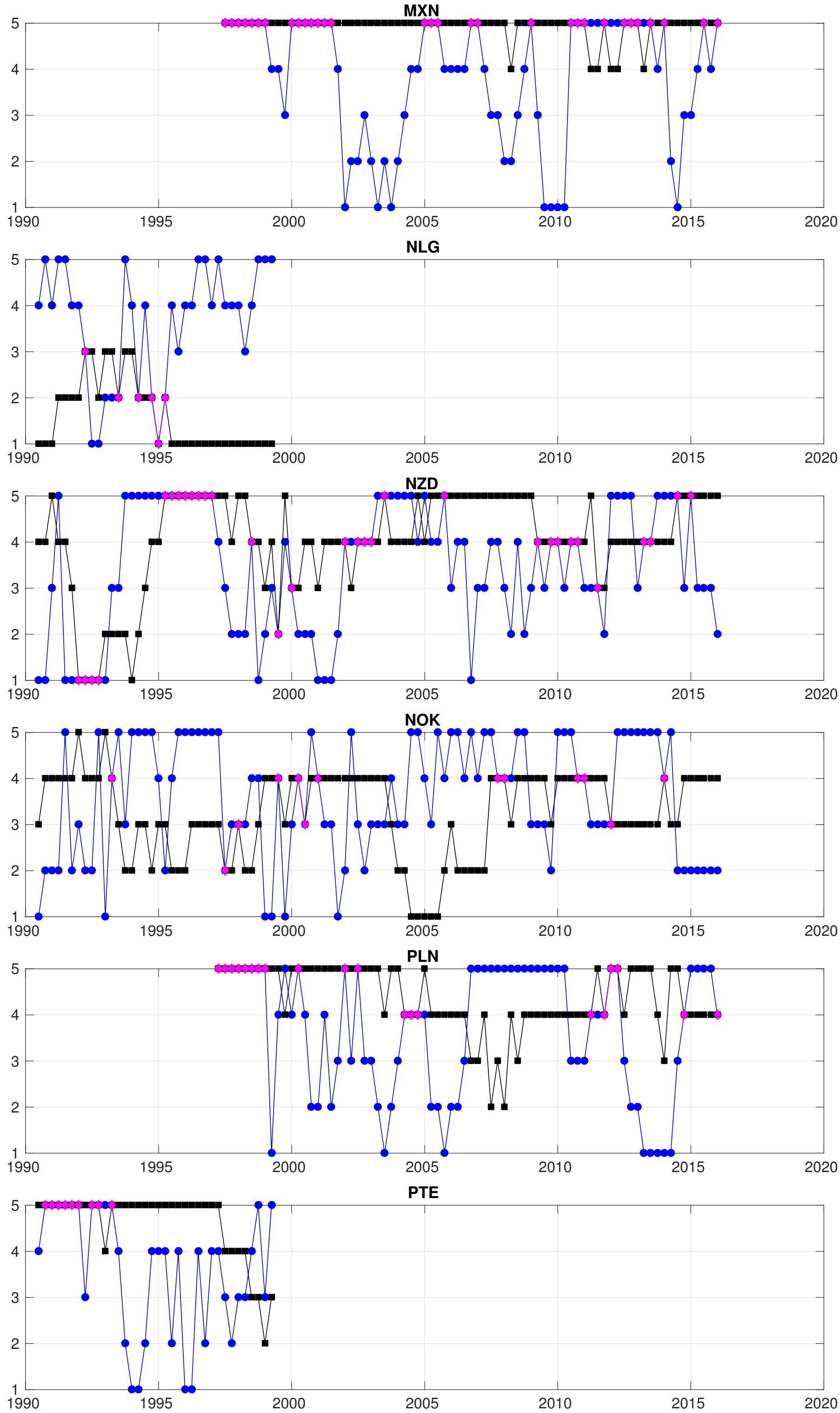
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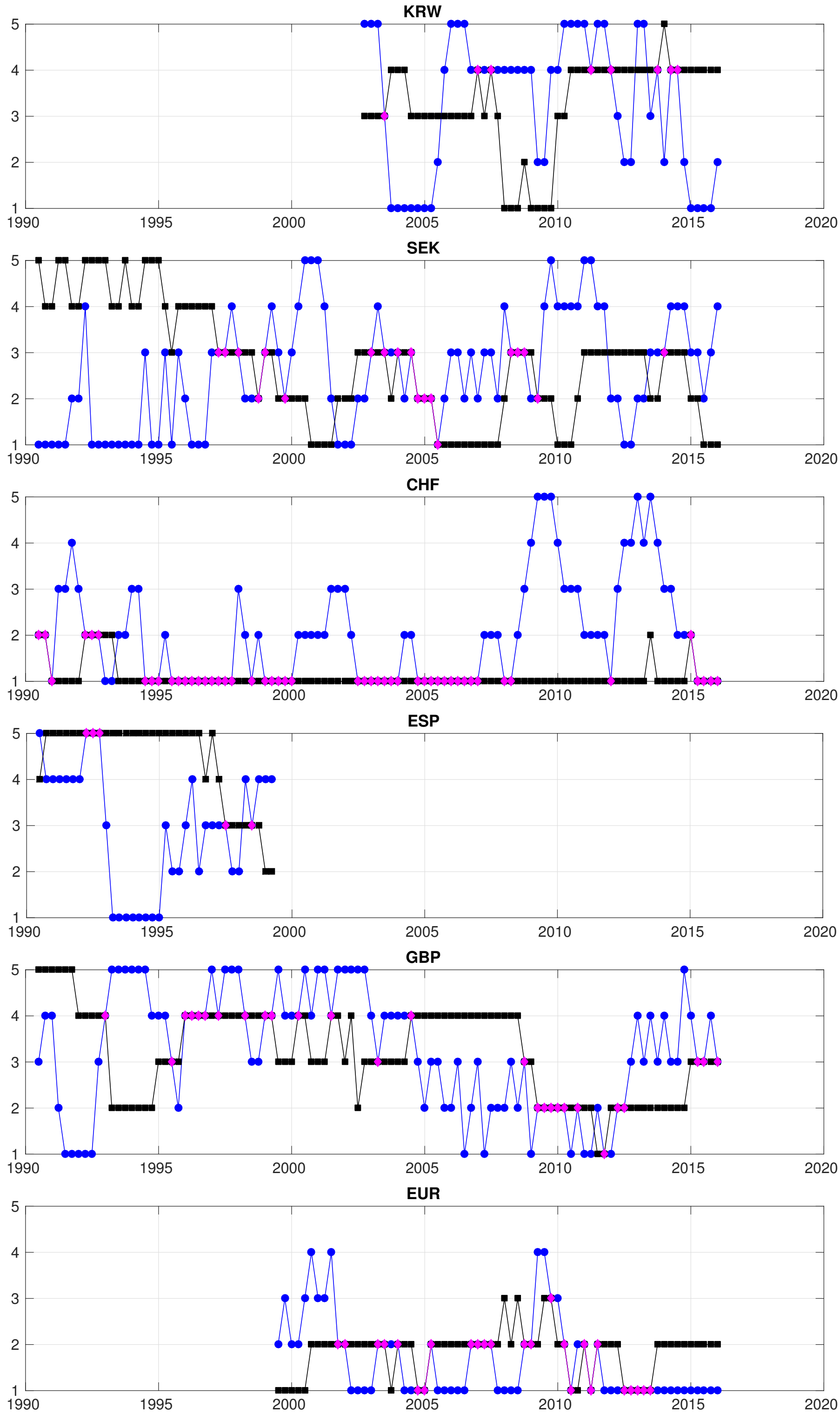


On the horizontal axis, the figures shows the quarters from 1990(1) to 2015(4). The vertical axis indicates the five currency portfolio, where the first portfolio is the "low" portfolio and the fifth portfolio is the "high" portfolio. The black squares indicate in which portfolio a particular currency is placed when currencies are sorted on forward discounts towards the USD. The blue dots indicate in which portfolio the currency falls if currencies are sorted on consumption growth rates. The mangenta colored diamonds indicate when the two sorts are identical.

A.3 Tables

Table A.1: Composition of consumption growth sorted portfolios

Quarter	low Δc_t portfolio					portfolio 2				portfolio 3				portfolio 4					high Δc_t portfolio				
1990_2	NZD	NOK	DKK	SEK		CHF	ITL	FRF		JPY	GBP	IEP		PTE	CAD	AUD	NLG		BEF	ATS	DEM	ESP	
1990_3	NZD	DKK	SEK	CAD		NOK	IEP	CHF		ITL	FRF	AUD		ESP	BEF	GBP	ATS		NLG	DEM	PTE	JPY	
1990_4	SEK	DKK	IEP	CHF		CAD	ITL	NOK		NZD	AUD	FRF		GBP	ESP	BEF	NLG		ATS	DEM	PTE	JPY	
1991_1	SEK	DKK	CAD	IEP		NOK	GBP	ITL		CHF	AUD	FRF		BEF	JPY	ESP	DEM		ATS	NZD	NLG	PTE	
1991_2	CAD	GBP	NZD	SEK		AUD	IEP	FRF		DKK	BEF	CHF		ESP	ITL	ATS	JPY		NOK	NLG	PTE	DEM	
1991_3	GBP	NZD	CAD	AUD		NOK	SEK	FRF		DKK	IEP	ITL		JPY	CHF	NLG	ESP		BEF	ATS	PTE	DEM	
1991_4	GBP	NZD	CAD	JPY		FRF	SEK	AUD		CHF	NOK	DEM		DKK	NLG	IEP	ESP		ATS	ITL	BEF	PTE	
1992_1	NZD	GBP	CAD	FRF		CHF	DKK	NOK		AUD	NLG	PTE		SEK	IEP	JPY	ITL		ATS	ESP	DEM	BEF	
1992_2	GBP	NZD	SEK	NLG		FRF	NOK	CHF		ITL	CAD	DEM		AUD	IEP	BEF	ATS		DKK	JPY	ESP	PTE	
1992_3	SEK	NLG	NZD	FRF		CHF	CAD	DEM		GBP	JPY	BEF		DKK	IEP	ATS	ITL		AUD	ESP	PTE	NOK	
1992_4	NZD	SEK	NOK	CHF		NLG	BEF	FRF		ESP	ITL	CAD		DKK	AUD	JPY	GBP		ATS	PTE	IEP	DEM	
1993_1	SEK	CHF	ESP	ITL		BEF	JPY	NLG		CAD	NZD	FRF		ATS	NOK	DKK	AUD		PTE	IEP	GBP	DEM	
1993_2	SEK	ITL	ESP	DKK		CHF	NLG	BEF		FRF	NZD	DEM		PTE	JPY	ATS	AUD		CAD	NOK	IEP	GBP	
1993_3	SEK	ITL	ESP	DKK		PTE	BEF	CHF		JPY	FRF	NOK		DEM	ATS	AUD	CAD		NLG	IEP	NZD	GBP	
1993_4	ITL	SEK	ESP	PTE		BEF	FRF	DKK		JPY	CHF	ATS		AUD	DEM	NLG	CAD		IEP	NZD	NOK	GBP	
1994_1	ITL	ESP	SEK	PTE		DEM	NLG	FRF		CHF	BEF	ATS		CAD	DKK	AUD	JPY		NZD	IEP	NOK	GBP	
1994_2	ESP	ITL	CHF	FRF		PTE	ATS	JPY		BEF	DEM	SEK		CAD	NLG	AUD	IEP		NOK	GBP	DKK	NZD	
1994_3	CHF	ESP	ITL	SEK		NLG	FRF	ATS		DEM	JPY	BEF		CAD	AUD	PTE	GBP		NOK	IEP	NZD	DKK	
1994_4	CHF	ESP	SEK	NLG		ATS	FRF	DEM		ITL	BEF	CAD		PTE	GBP	NOK	JPY		IEP	AUD	NZD	DKK	
1995_1	JPY	DEM	FRF	ATS		NLG	CHF	NOK		ESP	SEK	BEF		GBP	ITL	PTE	CAD		AUD	IEP	DKK	NZD	
1995_2	BEF	JPY	SEK	CHF		PTE	ESP	ATS		DEM	GBP	CAD		FRF	ITL	NOK	NLG		DKK	IEP	AUD	NZD	
1995_3	BEF	CHF	ATS	ITL		DKK	ESP	GBP		NLG	SEK	CAD		JPY	PTE	FRF	IEP		DEM	NOK	NZD	AUD	
1995_4	JPY	CHF	PTE	ATS		DKK	BEF	SEK		FRF	ESP	ITL		GBP	DEM	CAD	NLG		AUD	IEP	NZD	NOK	
1996_1	CHF	SEK	ITL	PTE		BEF	ATS	FRF		DKK	DEM	CAD		ESP	GBP	JPY	NLG		AUD	NZD	IEP	NOK	
1996_2	ATS	CHF	SEK	DEM		ITL	ESP	BEF		FRF	CAD	DKK		JPY	AUD	GBP	PTE		NLG	NZD	IEP	NOK	
1996_3	FRF	DEM	SEK	CHF		ATS	ITL	PTE		JPY	DKK	ESP		BEF	CAD	AUD	GBP		NLG	NOK	NZD	IEP	
1996_4	ITL	CHF	DEM	ATS		JPY	CAD	BEF		DKK	SEK	ESP		AUD	FRF	NLG	PTE		GBP	NZD	NOK	IEP	
1997_1	DEM	ITL	ATS	CHF		FRF	BEF	DKK	JPY	ESP	SEK	AUD		CAD	PTE	GBP	NZD		NLG	NOK	PLN	IEP	
1997_2	FRF	ATS	CHF	ITL	DEM	BEF	DKK	NOK	AUD	SEK	NZD	PTE	ESP	JPY	GRD	NLG	CAD		IEP	CZK	GBP	MXN	PLN
1997_3	JPY	ATS	FRF	CHF	DEM	ESP	BEF	PTE	NZD	CZK	ITL	AUD	NOK	DKK	SEK	NLG	CAD		GRD	GBP	IEP	MXN	PLN
1997_4	FRF	DEM	ATS	JPY	DKK	ESP	BEF	CZK	NZD	CHF	SEK	NOK	PTE	GRD	NLG	ITL	AUD		GBP	CAD	IEP	MXN	PLN
1998_1	JPY	DEM	CZK	ATS	BEF	CHF	NZD	FRF	SEK	NOK	PTE	NLG	ITL	ESP	CAD	DKK	GBP		GRD	AUD	MXN	PLN	IEP
1998_2	JPY	CZK	DEM	CHF	ATS	DKK	HUF	BEF	SEK	CAD	FRF	GBP	ESP	PTE	NZD	NOK	NLG	ITL	AUD	GRD	PLN	MXN	IEP
1998_3	CZK	JPY	DEM	DKK	NZD	SEK	CHF	BEF	ITL	ATS	CAD	GBP	FRF	NOK	AUD	GRD	HUF	ESP	PLN	PTE	NLG	MXN	IEP
1998_4	CZK	JPY	DEM	CHF	NOK	CAD	ITL	BEF	NZD	ATS	SEK	DKK	PTE	GRD	FRF	AUD	ESP	GBP	HUF	MXN	PLN	NLG	IEP

Quarter	low Δc_t portfolio					portfolio 2				portfolio 3				portfolio 4					high Δc_t portfolio				
1999_1	JPY	NOK	CZK	PLN	CHF	DEM	DKK	CAD	ATS	BEF	ITL	GRD	NZD	MXN	FRF	ESP	SEK	GBP	AUD	IEP	PTE	NLG	HUF
1999_2	JPY	DKK	CHF			NZD	EUR	CZK		GRD	CAD	SEK		MXN	NOK	PLN			GBP	HUF	AUD		
1999_3	DKK	NOK	CHF			JPY	CZK	SEK		MXN	EUR	GRD		CAD	NZD	GBP			PLN	AUD	HUF		
1999_4	DKK	JPY	CHF			EUR	GRD	CZK		SEK	NOK	NZD		CAD	GBP	PLN			AUD	MXN	HUF		
2000_1	DKK	JPY	CZK			CHF	NZD	EUR		GRD	CAD	AUD		SEK	GBP	NOK			MXN	HUF	PLN		
2000_2	DKK	JPY	CZK			NZD	CHF	GRD		NOK	EUR	AUD		PLN	HUF	CAD			MXN	SEK	GBP		
2000_3	JPY	DKK	CZK			NZD	CHF	PLN		GRD	HUF	AUD		EUR	CAD	GBP			NOK	MXN	SEK		
2000_4	JPY	DKK	NZD			CHF	PLN	HUF		CZK	GRD	EUR		AUD	CAD	NOK			GBP	MXN	SEK		
2001_1	DKK	JPY	NZD			GRD	CHF	CZK		EUR	NOK	AUD		HUF	PLN	SEK			CAD	GBP	MXN		
2001_2	DKK	JPY	NZD			PLN	SEK	CZK		CHF	NOK			EUR	GBP	HUF			CAD	AUD	MXN		
2001_3	DKK	SEK	NOK			NZD	EUR	JPY		PLN	CHF			MXN	CAD	CZK			AUD	GBP	HUF		
2001_4	SEK	DKK	MXN			CAD	NOK	EUR		CHF	JPY			NZD	AUD	CZK			PLN	GBP	HUF		
2002_1	DKK	SEK	EUR			MXN	JPY	CHF		PLN	CAD			AUD	CZK	NZD			NOK	GBP	HUF		
2002_2	JPY	EUR	CHF			MXN	DKK	SEK		AUD	NOK			NZD	CAD	CZK			PLN	GBP	HUF		
2002_3	DKK	CHF	EUR			JPY	NOK	SEK		MXN	CZK	PLN		AUD	NZD	CAD			GBP	HUF	KRW		
2002_4	CHF	EUR	DKK			MXN	JPY	CZK		SEK	PLN	NOK		GBP	NZD	CAD			AUD	KRW	HUF		
2003_1	CHF	MXN	JPY			EUR	PLN	DKK		CZK	GBP	NOK		CAD	SEK	AUD			NZD	KRW	HUF		
2003_2	CHF	DKK	PLN			JPY	MXN	EUR		KRW	NOK	SEK		GBP	CAD	AUD			CZK	NZD	HUF		
2003_3	KRW	MXN	CHF			JPY	EUR	PLN		DKK	SEK	CAD		AUD	NOK	GBP			CZK	NZD	HUF		
2003_4	KRW	JPY	CHF			MXN	EUR	DKK		PLN	SEK	NOK		CAD	AUD	GBP			CZK	NZD	HUF		
2004_1	KRW	EUR	JPY			CHF	SEK	CAD		MXN	DKK	NOK		PLN	GBP	CZK			AUD	HUF	NZD		
2004_2	KRW	HUF	EUR			CHF	JPY	CZK		CAD	SEK	DKK		MXN	GBP	PLN			NOK	AUD	NZD		
2004_3	KRW	JPY	EUR	CHF		SEK	CAD	CZK		GBP	HUF	DKK		PLN	ILS	MXN	NZD		AUD	NOK	EEK	ISK	
2004_4	KRW	EUR	JPY	CHF		SEK	CAD	GBP		ILS	HUF	CZK		PLN	EEK	DKK	NOK		AUD	MXN	NZD	ISK	
2005_1	JPY	HUF	CHF	KRW		EUR	SEK	PLN		CAD	GBP	NOK		CZK	AUD	NZD	DKK		ILS	MXN	ISK	EEK	
2005_2	JPY	CHF	EUR	SEK		KRW	PLN	AUD		DKK	CAD	GBP		NZD	CZK	ILS	HUF		NOK	MXN	EEK	ISK	
2005_3	JPY	CHF	EUR	PLN		HUF	GBP	SEK		CZK	AUD	CAD		KRW	ILS	NOK	MXN		DKK	NZD	EEK	ISK	
2005_4	HUF	CHF	JPY	EUR		PLN	CZK	GBP		AUD	SEK	NZD		CAD	MXN	ILS	DKK		KRW	NOK	EEK	ISK	
2006_1	DKK	ILS	EUR	CHF		AUD	JPY	PLN		GBP	SEK	CZK		MXN	CAD	HUF	NZD		NOK	KRW	ISK	EEK	
2006_2	CHF	GBP	JPY	EUR		HUF	SEK	CZK		PLN	AUD	CAD		ILS	NZD	NOK	MXN		DKK	KRW	ISK	EEK	
2006_3	HUF	CHF	JPY	NZD		EUR	GBP	ISK		AUD	SEK	CAD		CZK	ILS	DKK	KRW		PLN	NOK	MXN	EEK	
2006_4	ISK	JPY	DKK	CHF		EUR	HUF	SEK		GBP	NZD	AUD		KRW	CZK	NOK	CAD		ILS	PLN	MXN	EEK	
2007_1	ISK	HUF	JPY	GBP		CHF	DKK	EUR		SEK	NZD	CZK		CAD	AUD	KRW	MXN		PLN	NOK	ILS	EEK	
2007_2	ISK	JPY	DKK	HUF		EUR	CHF	GBP		SEK	MXN	CAD		NZD	KRW	CZK	AUD		NOK	PLN	ILS	EEK	
2007_3	DKK	HUF	JPY	EUR		GBP	CHF	SEK		MXN	CZK	CAD		NZD	NOK	KRW	AUD		PLN	ISK	EEK	ILS	
2007_4	HUF	JPY	EUR	CHF		MXN	DKK	GBP		CZK	CAD	NZD		SEK	NOK	KRW	AUD		PLN	EEK	ILS	ISK	

Quarter	low Δc_t portfolio				portfolio 2			portfolio 3			portfolio 4				high Δc_t portfolio			
2008_1	JPY	HUF	EUR	CHF	MXN	NZD	DKK	CZK	GBP	SEK	KRW	CAD	NOK	EEK	AUD	PLN	ILS	ISK
2008_2	EEK	HUF	JPY	EUR	CHF	CZK	GBP	SEK	DKK	MXN	NZD	ILS	AUD	KRW	NOK	CAD	PLN	ISK
2008_3	ISK	EEK	JPY	ILS	HUF	EUR	NZD	GBP	CHF	SEK	KRW	MXN	AUD	DKK	CZK	NOK	CAD	PLN
2008_4	ISK	EEK	GBP	HUF	JPY	SEK	EUR	NZD	NOK	DKK	AUD	ILS	KRW	CHF	MXN	CZK	CAD	PLN
2009_1	ISK	EEK	DKK	HUF	GBP	KRW	SEK	JPY	MXN	NOK	EUR	AUD	NZD	CAD	ILS	CHF	CZK	PLN
2009_2	ISK	EEK	MXN	HUF	DKK	KRW	GBP	NZD	JPY	NOK	EUR	SEK	CAD	AUD	ILS	CHF	CZK	PLN
2009_3	EEK	ISK	MXN	HUF	DKK	GBP	NOK	EUR	ILS	JPY	CAD	KRW	CZK	NZD	SEK	AUD	CHF	PLN
2009_4	EEK	ISK	HUF	MXN	DKK	GBP	CZK	EUR	JPY	CAD	NZD	KRW	SEK	CHF	AUD	NOK	ILS	PLN
2010_1	EEK	HUF	CZK	MXN	GBP	EUR	DKK	NZD	CHF	CAD	JPY	SEK	AUD	ISK	PLN	NOK	ILS	KRW
2010_2	EEK	HUF	GBP	EUR	ISK	CZK	DKK	CHF	PLN	AUD	CAD	JPY	SEK	NZD	ILS	MXN	NOK	KRW
2010_3	HUF	EEK	ISK	DKK	CZK	EUR	GBP	CHF	JPY	PLN	SEK	AUD	NZD	NOK	CAD	KRW	ILS	MXN
2010_4	ISK	HUF	DKK	GBP	CZK	EUR	CHF	EEK	NZD	PLN	NOK	CAD	JPY	AUD	SEK	KRW	ILS	MXN
2011_1	HUF	GBP	EUR	DKK	CZK	CHF	JPY	NZD	ISK	NOK	PLN	EEK	KRW	CAD	AUD	SEK	ILS	MXN
2011_2	DKK	JPY	HUF	CZK	CHF	GBP	EUR	ISK	NZD	NOK	SEK	CAD	PLN		KRW	MXN	AUD	ILS
2011_3	GBP	EUR	JPY	CZK	DKK	CHF	NZD	HUF	CAD	NOK	SEK	PLN	AUD		KRW	ISK	ILS	MXN
2011_4	GBP	EUR	JPY	CHF	DKK	CZK	SEK	HUF	NOK	CAD	KRW	ISK	ILS		AUD	PLN	NZD	MXN
2012_1	EUR	HUF	CZK	DKK	GBP	SEK	JPY	CHF	KRW	CAD	ILS	ISK	AUD		NOK	PLN	NZD	MXN
2012_2	EUR	CZK	HUF	SEK	DKK	KRW	GBP	PLN	CAD	ILS	CHF	AUD	ISK		NOK	JPY	NZD	MXN
2012_3	HUF	CZK	EUR	SEK	DKK	KRW	PLN	CAD	GBP	ISK	ILS	AUD	CHF		NZD	JPY	NOK	MXN
2012_4	HUF	EUR	CZK	DKK	PLN	SEK	JPY	ISK	ILS	NZD	CAD	GBP	AUD		KRW	CHF	MXN	NOK
2013_1	CZK	EUR	HUF	PLN	DKK	JPY	SEK	ISK	CAD	GBP	AUD	NZD	CHF		KRW	NOK	ILS	MXN
2013_2	EUR	HUF	PLN	CZK	ISK	AUD	DKK	JPY	KRW	SEK	GBP	CAD	NZD		CHF	ILS	NOK	MXN
2013_3	EUR	DKK	PLN	ISK	HUF	CZK	AUD	JPY	GBP	SEK	KRW	MXN	CHF		CAD	NOK	NZD	ILS
2013_4	EUR	DKK	PLN	HUF	CZK	ISK	KRW	JPY	CHF	SEK	AUD	GBP	NOK		MXN	CAD	NZD	ILS
2014_1	DKK	EUR	HUF	PLN	ISK	MXN	CZK	JPY	CHF	GBP	KRW	SEK	AUD		NOK	CAD	NZD	ILS
2014_2	DKK	MXN	EUR	HUF	CZK	NOK	CHF	PLN	ISK	GBP	SEK	CAD	KRW		NZD	AUD	ILS	JPY
2014_3	JPY	DKK	EUR	CZK	CHF	KRW	NOK	HUF	NZD	MXN	PLN	CAD	SEK		ILS	GBP	AUD	ISK
2014_4	JPY	EUR	DKK	KRW	CHF	CZK	NOK	SEK	HUF	MXN	GBP	CAD	AUD		ISK	PLN	NZD	ILS
2015_1	JPY	KRW	CHF	EUR	DKK	NOK	CZK	GBP	SEK	NZD	MXN	HUF	CAD		AUD	PLN	ISK	ILS
2015_2	JPY	CHF	KRW	EUR	NOK	SEK	CAD	NZD	DKK	GBP	CZK	AUD	HUF		MXN	PLN	ISK	ILS
2015_3	JPY	CHF	KRW	EUR	DKK	CAD	NOK	SEK	HUF	NZD	AUD	MXN	GBP		CZK	PLN	ISK	ILS
2015_4	JPY	CHF	CAD	EUR	NOK	NZD	KRW	DKK	GBP	AUD	SEK	PLN	CZK		MXN	HUF	ILS	ISK

Table A.2: Forward discount sorted currency portfolios

portfolio j	low	2	3	4	high	HML_{FX}
	excess return rx^j					
mean portfolio return	-1.5280	0.8594	1.4528	1.9717	3.5378	5.0657
std portfolio return	16.4668	18.5279	18.0586	18.8025	18.7177	17.2944
Sharpe ratio	-0.0928	0.0464	0.0804	0.1049	0.1890	0.2929
skewness	0.3760	0.1597	-0.3056	-0.3887	-0.7232	-0.6053
	spot change Δs^k					
mean	-0.2878	0.7009	0.4610	-0.3855	-2.7980	
std	16.2655	18.2173	17.9384	18.7193	18.8307	
	consumption growth Δc^j					
mean	1.8327	2.2189	2.8245	2.7964	2.4266	
std	1.1539	1.6288	1.7372	1.5447	3.1348	
	forward discount: $f^j - s^j$					
mean	-0.0031	0.0004	0.0025	0.0059	0.0158	
std	0.0044	0.0045	0.0044	0.0043	0.0081	

This table presents descriptive statistics of USD returns of five currency portfolios. Portfolios are constructed by sorting currencies according to their forward discounts against the US dollar; portfolios are rebalanced quarterly. The first portfolio always contains currencies of countries with the lowest fifth of forward discounts (interest rate differentals towards the USD), and the last portfolio always contains currencies of countries with the highest fifth of forward discounts. The last column shows descriptive statistics for the carry trade portfolio HML_{FX} which is given by a short position in all currencies of the low forward discount (interest rate) portfolio and a long position in the currencies of the high forward discount (interest rate) portfolio. Portfolio excess returns are calculated as $rx^j_{t+1} = f^j_{t,} - s^j_t - \Delta s^j_{t+1}$, where rx^j_{t+1} is the average return from borrowing in US dollars and investing in equal weights in all currencies of portfolio j. f^j_t is the log 3M forward exchange rate of the currencies in portfolio j against the US dollar, and Δs^j_{t+1} is the log difference of the spot exchange rates between dates t and $t+1$; an increase in s^j corresponds to a depreciation of the currencies in portfolio j against the US dollar. Quarterly returns are calculated using average forward and spot exchange rates over the last ten trading days of each quarter. The statistics are presented in percentages per annum, except for the forward discounts. The sample encompasses data for 29 OECD countries and it spans the period from the first quarter of 1990 to the fourth quarter of 2015.

Table A.3: Exchange rate returns – factor betas

	a^j	$\beta^j_{\overline{\mathrm{rx}}}$	$\beta^j_{\mathrm{HML}_{\Delta c}}$	$\overline{R}^2$
low	−0.0026	1.0010	−0.4455	
	(−1.1479)	(18.8339)	(−7.9354)	0.90
2	−0.0031	0.9515	−0.2032	
	(−1.2982)	(11.0993)	(−2.9578)	0.79
3	−0.0055	1.0420	−0.0730	
	(−3.3591)	(32.5539)	(−1.4484)	0.88
4	−0.0043	0.9527	0.1905	
	(−2.3211)	(22.1449)	(5.0132)	0.85
high	−0.0069	1.0139	0.4969	
	(−3.8492)	(22.2416)	(10.7819)	0.92

This table shows estimates and t-statistics obtained from running the following time series regression for each currency portfolio j separately:

$$\Delta s^j_{t+1} \quad = \quad a^j + \beta^j_{\overline{\mathrm{rx}}} \cdot \overline{\mathrm{rx}}_{t+1} + \beta^j_{\mathrm{HML}_{\Delta c}} \cdot \mathrm{HML}_{\Delta c,t+1} + \varepsilon^j_{t+1}$$

Standard errors are corrected for serial correlation using the Newey and West (1987) estimator for the covariance matrix of the error terms ε^j_{t+1}.

Table A.4: Exchange rate returns – risk price and factor loadings

	$\lambda_{\overline{\text{rx}}}$	$\lambda_{\text{HML}_{\Delta c}}$	$b_{\overline{\text{rx}}}$	$b_{\text{HML}_{\Delta c}}$
OLS estimate	-0.0015	0.0033	-0.6060	3.5303
t-stat	(-0.3557)	(1.0759)	(-0.2308)	(1.0032)
pricing error test		0.81		0.78
R^2		0.75		0.75
GLS estimate	-0.0015	0.0032	-1.0256	2.9347
t-stat	(-0.3488)	(1.0080)	(-0.4067)	(0.9854)
pricing error test		0.86		0.85

This first two columns of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad \beta^j_{\overline{\text{rx}}} \cdot \lambda_{\overline{\text{rx}}} + \beta^j_{\text{HML}_{\Delta c}} \cdot \lambda_{\text{HML}_{\Delta c}} + \alpha^j$$

$\beta^j_{\overline{\text{rx}}}$ and $\beta^j_{\text{HML}_{\Delta c}}$ correspond to the estimates obtained from running time series regressions of portfolio returns on the risk factors as reported in Table (A.3). Here, the factor βs and the prices of risk $\lambda_{\overline{\text{rx}}}$ and $\lambda_{\text{HML}_{\Delta c}}$ are estimated jointly using GMM. This approach yields standard errors which correct for the fact that the βs are estimates. The third and the fourth column of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad cov(\overline{\text{rx}}, rx^j) \cdot b_{\overline{\text{rx}}} + cov(\text{HML}_{\Delta c}, rx^j) \cdot b_{\text{HML}_{\Delta c}} + \alpha^j$$

where again, covariances and factor loadings b have been estimated jointly using GMM.R^2 statistics are calculated as described in the notes of table (2.4). The pricing error test reports the p-value for the null that the pricing errors are jointly zero.

Table A.5: Currency portfolios sorted on $\beta_{\text{HML}_{\Delta c,t}}$

portfolio j	low	2	3	4	high
	excess return rx^k				
mean	-0.8730	-1.1905	0.3053	1.5036	0.2951
std	18.4731	18.6700	19.6908	18.3606	16.5088
Sharpe ratio	-0.0473	-0.0638	0.0155	0.0819	0.0179
skewness	0.4305	0.2910	-0.4671	-0.6389	-0.9038
	spot change Δs^k				
mean	0.4710	-1.0155	-0.3250	-0.0818	-2.3259
std	18.2550	18.4025	19.4906	18.1561	16.0220
	consumption growth Δc^j				
mean	1.2903	2.3022	2.3087	2.9328	3.0393
std	1.8209	1.2261	1.3307	1.6721	1.8443
	forward discount: $f^j - s^j$				
mean	-0.0034	-0.0004	0.0016	0.0040	0.0066
std	0.0042	0.0040	0.0044	0.0047	0.0064

This table presents descriptive statistics of USD returns of five currency portfolios. Currencies are sorted into portfolios according to their β_t with respect to the consumption carry trade factor $\text{HML}_{\Delta c}$. For each currency k we estimate the following regression over rolling windows

$$rx^k_{t+1} = a^k + \beta^k_1 \cdot \overline{\text{rx}}_{t+1} + \beta^k_2 \cdot \text{HML}_{\Delta c,t+1} + \varepsilon^k_{t+1}$$

At time t, we run the regression using data for the quarters from $t-19$ to t (20 quarters). Due to the rolling window estimation, five years are lost, such that the data sample reaches from 1995(1) to 2015(4). The consumption carry trade factor $\text{HML}_{\Delta c}$ is constructed as described in the main text, based on five previous years consumption growth sorted currency portfolios. $\overline{\text{rx}}_{t+1}$ is the average return obtained from borrowing in US dollars and investing in equal weights in all currencies of the sample at a given point in time. Portfolio excess returns are calculated as $rx^j_{t+1} = f^j_{t+1} - s^j_t - \Delta s^j_{t+1}$, where rx^j_{t+1} is the average quarterly return from borrowing in US dollars and investing in equal weights in all currencies of portfolio j. f^j_{t+1} is the log 3M forward exchange rate of the currencies in portfolio j against the US dollar, and Δs^j_{t+1} is the log difference of the spot exchange rate between dates t and $t+1$; an increase in s^j corresponds to a depreciation of the currencies in portfolio j against the US dollar. Quarterly returns are calculated using average forward and spot exchange rates over the last ten trading days of each quarter. The statistics are presented in percentages per annum, except for the forward discounts. The sample encompasses data for 29 OECD countries and it spans the period from the first quarter of 1990 to the fourth quarter of 2015.

Table A.6: Forward discount factor betas

	a^j	$\beta^j_{\overline{\mathrm{rx}}}$	$\beta^j_{\mathrm{HML}_{\Delta c}}$	$\beta^j_{(\mathrm{f-s})}$	$\overline{R}^2$
low	0.0012	1.0193	−0.4824	−0.2930	
	(0.9520)	(22.5736)	(−10.7603)	(−1.6266)	0.94
2	−0.0010	0.9585	−0.1968	0.2631	
	(−0.3534)	(11.4556)	(−2.9484)	(0.6648)	0.79
3	−0.0015	1.0518	−0.0791	−0.0010	
	(−1.0740)	(27.4906)	(−1.3426)	(−0.1030)	0.88
4	0.0008	0.9582	0.1826	−0.0344	
	(0.4130)	(21.9233)	(4.2897)	(−0.9747)	0.84
high	0.0004	1.0111	0.5244	0.0104	
	(0.2848)	(21.4641)	(11.1407)	(1.9538)	0.93

This table shows estimates and t-statistics obtained from running the following time series regression for each currency portfolio j separately:

$$rx^j_{t+1} = a^j + \beta^j_{\overline{\mathrm{rx}}} \cdot \overline{\mathrm{rx}}_{t+1} + \beta^j_{\mathrm{HML}_{\Delta c}} \cdot \mathrm{HML}_{\Delta c,t+1} + \beta^j_{(f-s)}(f^j_t - s^j_t) + \varepsilon^j_{t+1}$$

Standard errors are corrected for serial correlation using the Newey and West (1987) estimator for the covariance matrix of the error terms ε^j_{t+1}.

Table A.7: Swiss investor – currency portfolios sorted on previous year consumption growth

portfolio j	low	2	3	4	high	$\overline{\text{rx}}$	$\text{HML}_{\Delta c}$
	excess return: rx^j						
mean	−0.5936	−0.6993	0.1818	1.6957	2.8262	0.7563	3.4198
std	14.3048	13.8867	15.0047	16.0968	17.7585	13.5409	12.5767
Sharpe ratio	−0.0415	−0.0504	0.0121	0.1053	0.1591	0.0559	0.2719
	spot change: Δs^j						
mean	3.1690	3.3488	2.7368	1.3018	1.2293		
std	14.3329	13.4734	14.9755	15.9044	17.3590		
	consumption growth: Δc^j						
mean	−0.2535	1.5810	2.4433	3.2817	5.0861		
std	2.4648	1.4247	1.3032	1.2679	1.7091		
	forward discount: $f^j - s^j$						
mean	0.0064	0.0067	0.0018	0.0049	−0.0036		
std	0.0043	0.0046	0.0540	0.0276	0.1003		

This table presents descriptive statistics of CHF returns of five currency portfolios. Portfolios are constructed by sorting currencies according to countries' consumption growth rate over the preceding year; portfolios are rebalanced quarterly. The first portfolio always contains currencies of countries with the lowest fifth of past consumption growth rates, and the last portfolio always contains currencies of countries with the highest fifth of past consumption growth rates. The second last column presents the average return obtained from borrowing in Swiss francs and investing in equal weights in all currencies of the sample, this return is labelled $\overline{\text{rx}}_{t+1}$. The last column shows descriptive statistics for the carry trade portfolio $\text{HML}_{\Delta c}$ which is given by a short position in all currencies of the low consumption growth portfolio and a long position in the currencies of the high consumption growth portfolio. Portfolio excess returns are calculated as $rx^j_{t+1} = f^j_t - s^j_t - \Delta s^j_{t+1}$, where rx^j_{t+1} is the average return from borrowing in Swiss francs and investing in equal weights in all currencies of portfolio j. f^j_t is the log 3M forward exchange rate of the currencies in portfolio j against the Swiss franc, and Δs^j_{t+1} is the log difference of the spot exchange rates between dates t and $t+1$; an increase in s^j corresponds to a depreciation of the currencies in portfolio j against the Swiss franc. Quarterly returns are calculated using average forward and spot exchange rates over the last ten trading days of each quarter. The statistics are presented in percentages per annum, except for the forward discounts. The sample encompasses data for 29 OECD countries and it spans the period from the first quarter of 1990 to the fourth quarter of 2015.

Table A.8: Swiss investor – factor betas

	a^j	$\beta^j_{\overline{\text{rx}}}$	$\beta^j_{\text{HML}_{\Delta c}}$	$\overline{R}^2$
low	0.0009	1.0543	−0.5177	
	(0.9036)	(23.0482)	(−15.0162)	0.99
2	−0.0024	0.8411	−0.1067	
	(−1.0964)	(7.1930)	(−1.7361)	0.62
3	−0.0016	0.9719	0.0200	
	(−0.8098)	(21.3685)	(0.3481)	0.77
4	0.0013	1.0482	0.1137	
	(0.6875)	(27.3443)	(2.0466)	0.83
high	0.0009	1.0543	0.4823	
	(0.9036)	(23.0482)	(13.9892)	0.94

This table shows estimates and t-statistics obtained from running the following time series regression for each currency portfolio j separately:

$$rx^j_{t+1} = a^j + \beta^j_{\overline{\text{rx}}} \cdot \overline{\text{rx}}_{t+1} + \beta^j_{\text{HML}_{\Delta c}} \cdot \text{HML}_{\Delta c,t+1} + \varepsilon^j_{t+1}$$

Standard errors are corrected for serial correlation using the Newey and West (1987) estimator for the covariance matrix of the error terms ε^j_{t+1}.

Table A.9: Swiss investor – risk price and factor loadings

	$\lambda_{\overline{\text{rx}}}$	$\lambda_{\text{HML}_{\Delta c}}$	$b_{\overline{\text{rx}}}$	$b_{\text{HML}_{\Delta c}}$
OLS estimate	0.0018	0.0092	-1.3392	9.8628
t-stat	(0.5847)	(3.1378)	(-0.4267)	(2.7941)
pricing error test		0.52		0.53
R^2		0.80		0.80
GLS estimate	0.0019	0.0088	-0.7423	7.9662
t-stat	(0.5923)	(2.8758)	(-0.2461)	(2.7504)
pricing error test		0.47		0.63

This first two columns of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad \beta^j_{\overline{\text{rx}}} \cdot \lambda_{\overline{\text{rx}}} + \beta^j_{\text{HML}_{\Delta c}} \cdot \lambda_{\text{HML}_{\Delta c}} + \alpha^j$$

$\beta^j_{\overline{\text{rx}}}$ and $\beta^j_{\text{HML}_{\Delta c}}$ correspond to the estimates obtained from running time series regressions of portfolio returns on the risk factors as reported in Table (A.8). Here, the factor βs and the prices of risk $\lambda_{\overline{\text{rx}}}$ and $\lambda_{\text{HML}_{\Delta c}}$ are estimated jointly using GMM. This approach yields standard errors which correct for the fact that the βs are estimates. The third and the fourth column of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad cov(\overline{\text{rx}}, rx^j) \cdot b_{\overline{\text{rx}}} + cov(\text{HML}_{\Delta c}, rx^j) \cdot b_{\text{HML}_{\Delta c}} + \alpha^j$$

where again, covariances and factor loadings b have been estimated jointly using GMM.R^2 statistics are calculated as described in the notes of table (2.4). The pricing error test reports the p-value for the null that the pricing errors are jointly zero. If the p-value is small, say less than 0.05, then pricing errors are significantly different from zero.

Table A.10: Most traded currencies – factor betas

	a^j	$\beta^j_{\overline{rx}}$	$\beta^j_{HML_{\Delta c}}$	$\overline{R}^2$
low	0.0014	0.9705	−0.5072	
	(1.6220)	(45.9095)	(−17.9742)	0.95
2	−0.0010	1.0530	−0.1227	
	(−0.4841)	(12.3630)	(−1.7062)	0.77
3	−0.0022	1.0463	0.1273	
	(−0.9865)	(15.4703)	(2.1535)	0.78
high	0.0014	0.9705	0.4928	
	(1.6220)	(45.9095)	(17.4652)	0.94

This table shows estimates and t-statistics obtained from running the following time series regression for each currency portfolio j separately:

$$rx^j_{t+1} \quad = \quad a^j + \beta^j_{\overline{rx}} \cdot \overline{rx}_{t+1} + \beta^j_{HML_{\Delta c}} \cdot HML_{\Delta c,t+1} + \varepsilon^j_{t+1}$$

Standard errors are corrected for serial correlation using the Newey and West (1987) estimator for the covariance matrix of the error terms ε^j_{t+1}.

Table A.11: Most traded currencies – risk price and factor loadings

	$\lambda_{\overline{\text{rx}}}$	$\lambda_{\text{HML}_{\Delta c}}$	$b_{\overline{\text{rx}}}$	$b_{\text{HML}_{\Delta c}}$
OLS estimate	0.0021	0.0104	2.2282	2.2282
t-stat	(0.5159)	(2.7266)	(0.6927)	(2.2519)
pricing error test		0.34		0.35
R^2		0.85		0.85
GLS estimate	0.0021	0.0106	3.3987	8.6529
t-stat	(0.5333)	(2.8289)	(1.0730)	(2.7149)
pricing error test		0.27		0.40

This first two columns of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad \beta^j_{\overline{\text{rx}}} \cdot \lambda_{\overline{\text{rx}}} + \beta^j_{\text{HML}_{\Delta c}} \cdot \lambda_{\text{HML}_{\Delta c}} + \alpha^j$$

$\beta^j_{\overline{\text{rx}}}$ and $\beta^j_{\text{HML}_{\Delta c}}$ correspond to the estimates obtained from running time series regressions of portfolio returns on the risk factors as reported in Table (A.11). Here, the factor βs and the prices of risk $\lambda_{\overline{\text{rx}}}$ and $\lambda_{\text{HML}_{\Delta c}}$ are estimated jointly using GMM. This approach yields standard errors which correct for the fact that the βs are estimates. The third and the fourth column of this table report results from estimating the following cross-sectional regression:

$$E(rx^j) \quad = \quad cov(\overline{\text{rx}}, rx^j) \cdot b_{\overline{\text{rx}}} + cov(\text{HML}_{\Delta c}, rx^j) \cdot b_{\text{HML}_{\Delta c}} + \alpha^j$$

where again, covariances and factor loadings b have been estimated jointly using GMM.R^2 statistics are calculated as described in the notes of table (2.4). The pricing error test reports the p-value for the null that the pricing errors are jointly zero. If the p-value is small, say less than 0.05, then pricing errors are significantly different from zero.

Appendix B

The Swiss franc's honeymoon

B.1 The Krugman (1991) model

Krugman (1991) considers a log-linear model of the exchange rate. Expressing all variables in natural logarithms, the exchange rate s equals

$$s_t = m_t + v_t + \gamma \frac{E_t(ds_t)}{dt} \tag{B.1}$$

where s is the spot price of foreign exchange and $E_t(\cdot)$ denotes expectation conditional on information available at time t. Further, there are two fundamentals in the exchange rate equation (B.1), the domestic money supply m and a shift term v. Monetary policy is passive; in the case of the Swiss franc, the central bank is prepared to increase m to prevent s from falling below the announced minimum level $\underline{s}$, but as long as s notes above $\underline{s}$, money supply remains unchanged. The only exogenous source of exchange rate dynamics is the shift term v. In Krugman's exposition of the model, v represents a velocity shock, but other interpretations of v allow for alternative models for the exchange rate. As we focus on the Swiss franc in its role as a safe haven currency, we chose variables that mirror global market sentiment as the exchange rate fundamentals. In particular, we set $v = -\kappa$, where a high κ indicates increased market risk. This leads to the following equation for the exchange rate

$$s_t = m_t - \kappa_t + \gamma \frac{E_t(ds_t)}{dt}. \tag{B.2}$$

Higher market risk κ now implies a lower s which corresponds to a more appreciated Swiss franc against the euro in our case. To solve the model, assume that κ follows a continuous-time random walk

$$d\kappa_t = \mu dt + \sigma dW_t \tag{B.3}$$

where μ is a constant predictable change in κ, dW is a standard Wiener process, and σ is a constant. This assumption implies that if markets expect no changes in m, that is, if there are no specific monetary policy rules in place, there will be no predictable changes in s. Using Itô's lemma and equation (B.2), depreciation during such a free float can be written as

$$\frac{1}{dt}E_t(ds_t) = s'(m_t - \kappa_t)\mu + s''(m_t - \kappa_t)\frac{1}{2}\sigma^2.$$

This leads to the following functional equation for the exchange rate:

$$s(m_t, \kappa_t) \quad = \quad (m_t - \kappa_t) + \gamma s'(m_t - \kappa_t)\mu + \gamma s''(m_t - \kappa_t)\frac{1}{2}\sigma^2. \tag{B.4}$$

The general solution to (B.4) is

$$s(m_t, \kappa_t) \quad = \quad (m_t - \kappa_t) + \gamma\mu + A\exp(\lambda_1(m_t - \kappa_t)) + B\exp(\lambda_2(m_t - \kappa_t)) \tag{B.5}$$

where $\lambda_1 > 0$ and $\lambda_2 < 0$.[1] A and B are constants of integration. If the exchange rate is allowed to float freely, s would simply equal the fundamental $(m - \kappa)$ and thus follow a random walk process, and we may set $A = B = 0$.

However, if the central bank announces to impose a lower limit $\underline{s}$ on the price of foreign exchange, the constants A and B are determined by the requirement that the exchange rate is insensitive to its fundamentals at the lower bound. This is required to preclude arbitrage opportunities as the exchange rate can move in one direction only once it notes at $\underline{s}$. Hence, while $s'(m - \kappa) \geq 0$ for $s > \underline{s}$, the boundary condition $s'(\underline{m - \kappa}) = 0$ implies $B > 0$.[2] With A equal zero and B being positive, equation (B.5) describes the exchange rate as a non-linear function of κ, whereby it is more sensitive to changes in κ the further away from the lower bound $\underline{s}$ it notes. At the lower bound, the expected change of s is positive, and because expected depreciation enters the basic exchange rate equation, this affects the exchange rate itself. The relationship between κ and s must be bent as s approaches its lower bound.

[1] λ_1 and λ_2 are the roots of the quadric equation in λ, $\lambda^2\gamma\sigma^2/2 + \lambda\gamma\mu - 1 = 0$, and are given by $\lambda_1 = \frac{-\mu + \sqrt{\mu^2 + 2\sigma^2/\gamma}}{\sigma^2} > 0$, and $\lambda_2 = \frac{-\mu - \sqrt{\mu^2 + 2\sigma^2/\gamma}}{\sigma^2} < 0$.

[2] A and B are determined by the requirement that the exchange rate function be tangent to its upper and lower bound: In the case of a one-sided target zone, there is no upper bound on the fundamental $(m - \kappa)$, i.e., $(\overline{m - \kappa}) \to \infty$. This implies $A \to 0$. B then is determined by $s'(\underline{m - \kappa}) = 0$, i.e. $0 = 1 + \lambda_2 B\exp(\lambda_2(\underline{m - \kappa}))$. With $\lambda_2 < 0$, this implies $B > 0$. Further, to preclude arbitrage opportunities, the exchange rate must spend no time on its lower bound. But as concerns the assumption that central bank interventions are infinitesimal at the bounds, Flood and Garber (1991) extend the model to allow for intra marginal discrete intervention policies; the behavior of the exchange rate within such a modified model remains almost unchanged.

B.2 Currency option prices

B.2.1 Option prices in over-the-counter currency markets

This Section first shows how option prices are quoted in over-the-counter (OTC) currency markets. Then, the Section proceeds to introduce three option portfolios that are frequently traded in these markets: at-the-money straddles, risk-reversals, and strangles summarize the position and the shape of the density function that option prices imply for the future exchange rate.

Pricing conventions

For our analysis, we download daily currency option price quotes from Bloomberg for the Swiss franc/euro exchange rate. Over-the-counter markets in which most currency option dealing takes place use conventions based on the Black-Scholes model to express the terms and prices of currency options.[3] The Black-Scholes formula for the value of a European currency call options is[4]

$$C(F,\tau) \quad = \quad (FN(d_1) - KN(d_2))\, e^{-r\tau} \tag{B.6}$$

and the value of a put is

$$P(F,\tau) \quad = \quad (F\,[N(d_1)-1] - K\,[N(d_2)-1])\, e^{-r\tau} \tag{B.7}$$

where τ is the time remaining until maturity expressed in years, F denotes the forward price of the deliverable currency, K is the strike price of the option, r is the domestic risk-free rate of interest, and $N(\cdot)$ denotes the cumulative normal distribution, and

$$\begin{aligned} d_1 &= \frac{\ln(F/K) + \sigma^2\tau/2}{\sigma\sqrt{\tau}} \\ d_2 &= \frac{\ln(F/K) - \sigma^2\tau/2}{\sigma\sqrt{\tau}} \end{aligned}$$

[3] The original exposition of the Black-Scholes model is Black and Scholes (1973). A very similar model was developed independently by Merton (1976). The application of the model to foreign currency options is also called the Garman-Kohlhagen model, after its publication by Garman and Kohlhagen (1983). (see Malz (1996), footnote 11.)

[4] See Garman and Kohlhagen (1983), or, for a textbook version, Hull (2012), chapter 14.

In currency markets, the only unobserved variable in equations (B.6) and (B.7) is the volatility of the price of the foreign currency σ. Alternatively, replacing the left-hand side of equations (B.6) and (B.7) with an observed option price allows to extract volatility as an implicit function of C_t or P_t, and F_t, τ, and K. In this context, σ is called the option implied volatility. The Black-Scholes values increase monotonically in σ, so the implied volatility is a unique inverse function of $C_t(F,\tau)$ or $P(F,\tau)$.

In over-the-counter currency markets, option quotes are made on implied volatilities rather than option prices denominated in currency units. Also, options are not specified by strike prices K, but by the option delta Δ which measures the degree to which options are in- or out-of-the-money. The delta of a put and a call is given by the derivative of the Black-Scholes option values with respect to the forward rate

$$
\begin{aligned}
\Delta_C &= \frac{\partial C(F,\tau)}{\partial F} \\
&= e^{-r\tau}N(d_1) \qquad \text{(B.8)} \\
\Delta_P &= \frac{\partial P(F,\tau)}{\partial F} \\
& \quad -e^{-r\tau}N(-d_1) \qquad \text{(B.9)}
\end{aligned}
$$

Hence, the delta of an option measures the sensitivity of the option price to the forward exchange rate and it takes on values between 0% and 100%. The delta of an at-the-money forward option, that is, the delta of an option of which the exercise price is set equal to the forward exchange rate of the same maturity as the option, is approximately 50 percent. Frequently traded are further options with a delta of 25, whereby a 25-delta call (put) corresponds to an option with a strike above (below) the strike of an at-the-money option.

Volatility smile

The Black-Scholes model would imply that all options on the same currency have the same implied volatility, regardless of time to maturity and moneyness. However, it turns out that σ differs across deltas and maturities for options on a given foreign currency. When regarding implied volatilities for a specific maturity only, one typically finds that the implied volatility is higher for options with a delta further away from 50 percent, that is, for options that are more deeply in-the-money or out-of-the-money. This pattern is referred to as the “volatility smile”.

Three instruments that are actively traded in over-the-counter currency option markets, *delta-neutral straddles*, *risk-reversals*, and *strangles* or *butterfly spreads*, summarize the position and shape of the volatility smile. Straddles and strangles both consist of buying or selling an equal number of call and put options on the same currency with the same time to maturity. A delta-neutral *straddle* consists of a portfolio in which both, the put and the call option are at-the-money. The price of this portfolio gives the at-the-money (atm) implied volatility, and it indicates the overall level of the volatility smile. A *strangle* is a portfolio of an out-of-the-money put and an out-of-the-money call with the same delta; most frequently, strangles with a delta of 25 percent are traded. Strangle prices are quoted as the spread of the average implied volatility at which the options are bought or sold over the at-the-money implied volatility:

$$str25 = \frac{\sigma(C25)+\sigma(P25)}{2} - atm$$

The strangle implied volatility indicates the degree of curvature of the volatility smile; hence, a strangle is a bet on a large move of the underlying currency either upwards or downwards. Eventually, the *risk-reversal* also consists of an out-of-the-money put and call, but in contrast to the strangle, the dealer exchanges one of the options for the other with the counterpart. Because the put and the call generally have different implied volatilities, the dealer pays or receives a premium for exchanging the options. The premium is expressed as the implied volatility spread at which a 25-delta call is exchanged for a 25-delta put and indicates the skewness of the volatility smile

$$rr25 = \sigma(C25) - \sigma(P25)$$

If a 25-delta call trades at a higher price than a 25-delta put such that the risk reversal is positive, this indicates that the market favors the foreign currency.

For our analysis, we download implied volatility quotes from Bloomberg for Swiss franc options on the euro in the form of at-the-money implied volatilities, 10- and 25-delta risk-reversals and 10- and 25-delta strangles. Given these quotes, we obtain the implied volatility of 25-delta put and call options as $\sigma(C25) = atm + str25 + \frac{1}{2}rr25$ and $\sigma(P25) = atm + str25 - \frac{1}{2}rr25$, and accordingly for 10-delta put and call options. Considering put-call parity,[5] Bloomberg hence provides us with implied volatility quotes for five levels of moneyness, namely for $\Delta = \{10, 25, 50, 75, 90\}$.

[5] Put-call parity implies that puts and calls with the same exercise price have identical implied volatilities, so the volatility of an x-delta put equals that of an $(1-x)$-delta call.

B.2.2 Interpolating the risk neutral distribution

To obtain the risk-neutral EUR/CHF density function, we follow the approach proposed by Malz (1997a) and interpolate the volatility smile.[6] His approach bases on the insight promoted by Breeden and Litzenberger (1978) according to which the discounted risk-neutral density function of the time T asset price equals the second derivative of the call option price function with respect to the exercise price

$$\frac{\partial^2 C(F,\tau;K,\sigma,r)}{\partial K^2} \quad = \quad e^{-r\tau}\pi(K) \tag{B.10}$$

To obtain a closely spaced series of call option prices with different exercise prices, which is needed to empirically implement equation (B.10), Malz proposes to first interpolate the volatility smile to obtain a series of implied volatility quotes across deltas, and then to use the Black-Scholes call option price formulas (B.6) and (B.8) to transform the option prices from the volatility-delta space to the cash price - strike price space. With the at-the-money implied volatility (atm), the risk reversal (rr), and the strangle (str) volatility price quotes indicating the level, the skewness and the kurtosis of the volatility smile respectively, Malz (1997a) proposes to approximate the implied volatility function by

$$\hat{\sigma}(\Delta) \quad = \quad b_0 atm_t + b_1 rr_t(\Delta - 0.50) + b_2 str_t(\Delta - 0.5)^2. \tag{B.11}$$

Imposing the condition that the at-the-money volatility and the risk-reversal and the strangle price lie exactly on $\hat{\sigma}(\Delta)$ allows to solve for $(b_1, b_2, b_3) = (1, -2, 16)$. Since delta itself is a function of the implied volatility, one can substitute equation (B.8) into equation (B.11) and solve for σ as a function of K. Having obtained implied volatilities for given strike prices, the call pricing function (B.6) eventually allows to substitute out cash call prices for given strike prices. The last step to obtain the risk-neutral probability distribution of strike prices at maturity requires to differentiate the call price function with respect to the strike prices. This is easiest done numerically by calculating simple finite differences. The estimated cumulative distribution function at point K is

$$\hat{\Pi}(K) \quad = \quad e^{-r\tau}\left(\frac{C(K) - C(K-h)}{h} + 1\right)$$

[6] The literature has presented a large number of techniques to estimate the option implied density function for future asset prices. Jackwerth (1999) for example provides an extensive survey.

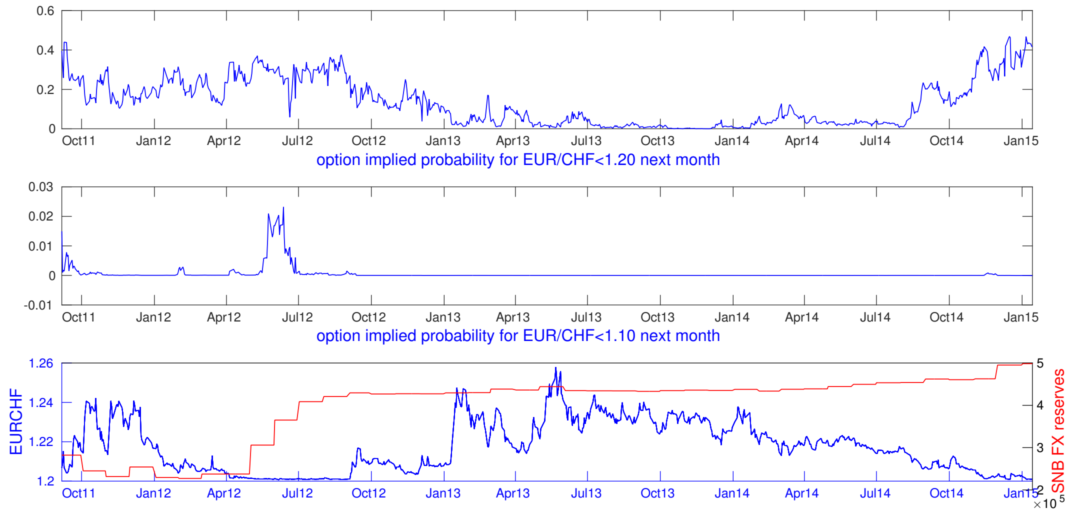
and the estimated probability density function is

$$\hat{\pi}(K) = \frac{\hat{\Pi}(K) - \hat{\Pi}(K-h)}{h}$$

where h is the step size between adjacent strike prices K. This is done for each K to draw the entire cumulative distribution or density function.

B.2.3 Option implied probability for EUR/CHF < 1.20

Figure B.1: Option prices implied probability for EUR/CHF $< 1.20\,(1.10)$ one month in the future



The figure plots the risk-neutral probability that the Swiss franc will note below 1.20 (1.10) to the euro at the expiration dates of European option contracts, which lie one month in the future. The risk-neutral density function for the Swiss franc price of the euro is obtained by interpolating the volatility smile as suggested by Malz (1997a).

Appendix C

Not that puzzling – consumption and relative prices within the EMU

C.1 The model

The Model

To set-up and solve the model, I follow Obsfeld and Rogoff (1996), chapter 5.5 and Hassan (2013).

Countries $k = 1 \dots K$ maximize lifetime utility

$$U_1^k = \frac{1}{1-\gamma}\left(C_1^k\right)^{(1-\gamma)} + e^{-\delta}\frac{1}{1-\gamma}E\left[\left(C_2^k\right)^{(1-\gamma)}\right] \tag{C.1}$$

The consumption index is defined as:

$$C_t^k = g(C_{T,t}^k, C_{N,t}^k) \equiv \left(\left(\tau C_{T,t}^k\right)^{\alpha} + (1-\tau)\left(C_{N,t}^k\right)^{\alpha}\right)^{\frac{1}{\alpha}} \tag{C.2}$$

$\tau\varepsilon(0,1)$ is the weight of the traded good in the consumption index, and $\varepsilon_\alpha = \frac{1}{1-\alpha}$ is the elasticity of substitution between traded and nontraded goods.

Call ω the realization of second period endowments and let $f(\omega)$ be the associated density. Countries take prices as given and maximize lifetime utility subject to their international budget constraint

$$\begin{aligned} P_1^k C_1^k + \int_\omega Q(\omega)\left((P_2^k(\omega) C_2^k(\omega)\right) d\omega & \\ \leq Y_{T,1}^k + P_{N,1}^k Y_{N,1}^k + \int_\omega \left(Q(\omega) Y_2^k(\omega) + Q(\omega) P_{N,2}^k(\omega) Y_{N,2}^k(\omega)\right) d\omega & \end{aligned}$$

Define $Q(\omega)$ to be the price, in terms of date 1 tradables, of a unit of tradables delivered on date 2 if and only if the state is ω. $P_{N,1}^k$ is the country k price of nontradables in terms of tradables on date 1, and $P_{N,2}^k(\omega)$ is the same relative price on date 2 in state ω. Thus, $Q(\omega)P_{N,2}^k(\omega)$ is the price of date 2, state ω, nontradables in terms of date 1 tradables. P_t^k is the price index of country k that prices the consumption index (C.2).

Countries' optimal behavior is characterized by the Euler equation

$$Q(\omega) = e^{-\delta}\frac{\Lambda_{T,2}(\omega)}{\Lambda_{T,1}} f(\omega) \quad \forall\omega$$

$\Lambda_{T,t} = \left(C_t^k\right)^{1-\gamma-\alpha}\left(C_{T,t}^k\right)^{\alpha-1}$ is countries' marginal utility from tradable consumption at time t. Since countries face a common set of Arrow-Debreu prices for state-contingent payments of tradables, Λ_T equalizes internationally.

Social Planner's Problem

To describe the optimal allocation of resources, solve the Social Planner's problem.

The economy's resource constraint is given by

$$\begin{aligned} C_N^k &= Y_N^k \quad \forall k \\ \sum_{k=1}^{K} C_T^k &= \sum_{k=1}^{K} Y_T^k \end{aligned}$$

and the associated Lagrangian is

$$\begin{aligned} L = & \sum_{k=1}^{K} \frac{1}{1-\gamma} \left(\left(\tau C_{T,t}^k \right)^{\alpha} + (1-\tau) \left(C_{N,t}^k \right)^{\alpha} \right)^{\frac{1-\gamma}{\alpha}} \\ & -\Lambda_T \left(\sum_{k=1}^{K} C_T^k - \sum_{k=1}^{K} Y_T^k \right) \\ & -\sum_{k=1}^{K} \Lambda_N^k \left(C_N^k - Y_N^k \right) \end{aligned}$$

which yields $2k$ first order conditions

$$\begin{aligned} \left(\left(\tau C_T^k \right)^{\alpha} + (1-\tau) \left(C_N^k \right)^{\alpha} \right)^{\frac{1-\gamma}{\alpha}-1} \tau \left(C_T^k \right)^{\alpha-1} &= \Lambda_T \quad \forall k \\ \left(\left(\tau C_T^k \right)^{\alpha} + (1-\tau) \left(C_N^k \right)^{\alpha} \right)^{\frac{1-\gamma}{\alpha}-1} (1-\tau) \left(C_N^k \right)^{\alpha-1} &= \Lambda_N^k \quad \forall k \end{aligned}$$

Deterministic Solution

Log-linearize these first order conditions around a deterministic steady state:

$$\begin{aligned} (1-\gamma-\alpha)(\tau c_T^k + (1-\tau) c_N^k) + \log \tau + (\alpha - 1) c_T^k &= \lambda_T \quad \forall k \\ (1-\gamma-\alpha)(\tau c_T^k + (1-\tau) c_N^k) + \log(1-\tau) + (\alpha - 1) c_N^k &= \lambda_N^k \quad \forall k \\ c_N^k &= y_N^k \quad \forall k \\ \sum_{k=1}^{K} c_T^k &= \sum_{k=1}^{K} y_T^k \end{aligned}$$

This system can be solved for $\{\lambda_T, \{c_T^k, c_N^k, \lambda_N^k\}_k\}$, and $p_N^k = \lambda_N^k - \lambda_T$.

plug in $c_k^N = y_k^N$

$$\begin{aligned}(1-\gamma-\alpha)(\tau c_T^k + (1-\tau)y_N^k) + \log\tau + (\alpha-1)c_T^k &= \lambda_T \quad \forall k \qquad \text{(C.3)}\\ (1-\gamma-\alpha)(\tau c_T^k + (1-\tau)y_N^k) + \log(1-\tau) + (\alpha-1)y_k^N &= \lambda_N^k \quad \forall k\end{aligned}$$

To solve this system, I consider a three-county-economy with $K = \{A, B, C\}$. Results can then be generalized to the $k = 1\ldots K$ country-case.

First, substitute for traded consumption of country A in equation (C.3) and use the fact that marginal utility from traded consumption is the same for all countries: $c_T^A = y_T^A + y_T^B + y_T^C - c_T^B - c_T^C$

$$\begin{aligned}(1-\gamma-\alpha)(\tau[y_T^A+y_T^B+y_T^C-c_T^B-c_T^C]+(1-\tau)y_N^A)+(\alpha-1)[y_T^A+y_T^B+y_T^C-c_T^B-c_T^C]\\ = (1-\gamma-\alpha)(\tau c_T^B+(1-\tau)y_N^B)+(\alpha-1)c_T^B \qquad \text{(C.4)}\end{aligned}$$

$$\begin{aligned}(1-\gamma-\alpha)(\tau[y_T^A+y_T^B+y_T^C-c_T^B-c_T^C]+(1-\tau)y_N^A)+(\alpha-1)[y_T^A+y_T^B+y_T^C-c_T^B-c_T^C]\\ = (1-\gamma-\alpha)(\tau c^C+(1-\tau)y_N^C)+(\alpha-1)c_T^C \qquad \text{(C.5)}\end{aligned}$$

solve equation (C.4) for c_T^B

$$\begin{aligned}&-\tau(1-\gamma-\alpha)c_T^B-(\alpha-1)c_T^B+(1-\gamma-\alpha)(\tau[y_T^A+y_T^B+y_T^C-c_T^C]+(1-\tau)y_N^A)+(\alpha-1)[y_T^A+y_T^B+y_T^C-c_T^C]\\
&\quad= \tau(1-\gamma-\alpha)c_T^B+(\alpha-1)c_T^B+(1-\gamma-\alpha)((1-\tau)y_N^B)\\
&(1-\gamma-\alpha)(\tau[y_T^A+y_T^B+y_T^C-c_T^C]+(1-\tau)y_N^A)+(\alpha-1)[y_T^A+y_T^B+y_T^C-c_T^C]-(1-\gamma-\alpha)((1-\tau)y_N^B)\\
&\quad= 2\tau(1-\gamma-\alpha)c_T^B+2(\alpha-1)c_T^B\\
&\left[\tau(1-\gamma-\alpha)[y_T^A+y_T^B+y_T^C-c_T^C]+(\alpha-1)[y_T^A+y_T^B+y_T^C-c_T^C]\right]+\left[(1-\gamma-\alpha)(1-\tau)\left(y_N^A-y_N^B\right)\right]\\
&\quad= 2(\tau(1-\gamma-\alpha)+\alpha-1)c_T^B\\
&\left\{\left(\tau(1-\gamma-\alpha)[y_T^A+y_T^B+y_T^C]+(\alpha-1)[y_T^A+y_T^B+y_T^C]\right)-(\tau(1-\gamma-\alpha)+\alpha-1)c_T^C\right\}+\left\{(1-\gamma-\alpha)(1-\tau)\left(y_N^A-y_N^B\right)\right\}\\
&\quad= 2(\tau(1-\gamma-\alpha)+\alpha-1)c_T^B\\
&\left\{[y_T^A+y_T^B+y_T^C](\tau(1-\gamma-\alpha)+\alpha-1)-(\tau(1-\gamma-\alpha)+\alpha-1)c_T^C\right\}+\left\{(1-\gamma-\alpha)(1-\tau)\left(y_N^A-y_N^B\right)\right\}\\
&\quad= 2(\tau(1-\gamma-\alpha)+\alpha-1)c_T^B\\
&[y_T^A+y_T^B+y_T^C]-c_T^C+\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(y_N^A-y_N^B\right)=2c_T^B\\
&\frac{1}{2}\left(y_T^A+y_T^B+y_T^C-c_T^C\right)+\frac{1}{2}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(y_N^A-y_N^B\right)=c_T^B\end{aligned}$$

solve equation (C.5) for c_T^B too:

$$
\begin{aligned}
(1-\gamma-\alpha)(\tau[y_T^A+y_T^B+y_T^C-c_T^C]+(\alpha-1)[y_T^A+y_T^B+y_T^C-c_T^C]+(1-\gamma-\alpha)(1-\tau)\left(y_N^A-y_N^C\right) \\
=(\tau(1-\gamma-\alpha)+\alpha-1)\,c_T^B+(\tau(1-\gamma-\alpha)+\alpha-1)\,c_T^C \\
\left((\tau(1-\gamma-\alpha)+\alpha-1)\,[y_T^A+y_T^B+y_T^C-c_T^C]\right)+(1-\gamma-\alpha)(1-\tau)\left(y_N^A-y_N^C\right) \\
=(\tau(1-\gamma-\alpha)+\alpha-1)\,c_T^B+(\tau(1-\gamma-\alpha)+\alpha-1)\,c_T^C \\
(\tau(1-\gamma-\alpha)+\alpha-1)\,[y_T^A+y_T^B+y_T^C]-2\,(\tau(1-\gamma-\alpha)+\alpha-1)\,c_T^C+(1-\gamma-\alpha)(1-\tau)\left(y_N^A-y_N^C\right) \\
=(\tau(1-\gamma-\alpha)+\alpha-1)\,c_T^B \\
=\left(y_T^A+y_T^B+y_T^C\right)-2c_T^C+\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\left(y_N^A-y_N^C\right)=c_T^B
\end{aligned}
$$

Set equal the two equations and solve for c_T^C.

$$
\begin{aligned}
\frac{1}{2}\left(y_T^A+y_T^B+y_T^C-c_T^C\right)+\frac{1}{2}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(y_N^A-y_N^B\right) \\
=\left(y_T^A+y_T^B+y_T^C\right)-2c_T^C+\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\left(y_N^A-y_N^C\right) \\
\frac{1}{2}\left(y_T^A+y_T^B+y_T^C\right)+\frac{1}{2}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(y_N^A-y_N^B\right)-\left(y_T^A+y_T^B+y_T^C\right)-\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\left(y_N^A-y_N^C\right)=\frac{1}{2}c_T^C-2c_T^C \\
-\frac{1}{2}\left(y_T^A+y_T^B+y_T^C\right)-\frac{1}{2}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)y_N^A-\frac{1}{2}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)y_N^B+\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)y_N^C=-\frac{3}{2}c_T^C \\
\frac{1}{3}\left(y_T^A+y_T^B+y_T^C\right)+\frac{1}{3}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(y_N^A+y_N^B\right)-\frac{2}{3}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)y_N^C=c_T^C \\
\frac{1}{3}\left(y_T^A+y_T^B+y_T^C\right)+\frac{1}{3}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(y_N^A+y_N^B-2y_N^C\right)=c_T^C \\
\frac{1}{3}\left(y_T^A+y_T^B+y_T^C\right)+\frac{1}{3}\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(\left(y_N^A-y_N^C\right)+\left(y_N^B-y_N^C\right)\right)=c_T^C
\end{aligned}
$$

so, for $k=1\ldots K$ countries, with country $j\varepsilon\{K\}$:

$$
\begin{aligned}
c_T^j &= \frac{1}{K}\sum_{k=1}^{K}y_T^k+\left(\frac{(1-\gamma-\alpha)(1-\tau)}{\tau(1-\gamma-\alpha)+\alpha-1}\right)\left(\frac{1}{K}\sum_{k=1}^{K}\left(y_N^k-y_N^j\right)\right) \\
c_T^j &= \frac{1}{K}\sum_{k=1}^{K}y_T^k+\left(\frac{1-\gamma-\alpha}{\alpha-\left(\frac{\tau}{1-\tau}\right)\gamma-1}\right)\left(\frac{1}{K}\sum_{k=1}^{K}\left(y_N^k-y_N^j\right)\right) \\
&= \overline{y_T}+\left(\frac{\left(\gamma-\left(\frac{1}{1-\alpha}\right)^{-1}\right)(1-\tau)}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right)\left(\overline{y_N}-y_N^j\right)
\end{aligned}
$$

Price Index

Solving the expenditure minimization problem produces an ideal price index in the sense that in maps the prices of individual goods and services into a single consumption deflator with the property that aggregate consumption is consistent with the utility concept defined by the structure of preferences [copied from Crucini and Landry (2012)]

The equilibrium cost of one unit of consumption in country k is defined as

$$P^k \quad = \quad \arg\min C_T^k + P_N^k C_N^k \quad \text{s.t. } C^k = 1$$

The first order conditions describe relative optimal consumption quantities as a function of their relative price:

$$C_N^k \quad = \quad \left(P_N^k\right)^{\frac{1}{\alpha-1}} \left(\frac{\tau}{1-\tau}\right)^{\frac{1}{\alpha-1}} C_T^k \tag{C.6}$$

Combining the constraint of this minimization problem with the consumption index (4.2), $g(C_T^k C_N^k) = 1$, together with the objective function allows to write

$$P^k \quad = \quad \frac{C_T^k + P_N^k C_N^k}{\left(\tau\left(C_T^k\right)^{\alpha} + (1-\tau)\left(C_N^k\right)^{\alpha}\right)^{\frac{1}{\alpha}}} \tag{C.7}$$

Combining equations (C.6) and (C.7) yields

$$P^k \quad = \quad \left(\tau^{\left(\frac{1}{1-\alpha}\right)} + (1-\tau)^{\left(\frac{1}{1-\alpha}\right)} \left(P_N^k\right)^{-\frac{\alpha}{1-\alpha}}\right)^{\left(-\frac{1-\alpha}{\alpha}\right)} \tag{C.8}$$

This deflator satisfies

$$P^k C^k \quad = \quad P_N^k C_N^k + C_T^k$$

where the quantities of aggregate consumption and consumption of individual goods and services are at the optimal levels chosen by consumers in country k, taking prices and income as given. [copied from Crucini and Landry (2012)]

log-linearizing the price index P^k yields

$$p^k \quad = \quad (1-\tau)p_N^k + \log\left(\frac{(1-\tau)^{\tau-1}}{\tau^{\tau}}\right)$$

Hence, the real exchange rate between any two countries i, j is

$$rer^{j,i} \equiv p^i - p^j \quad = \quad (1-\tau)(p_N^i - p_N^j)$$

As is the case in the model with separable utility, the real exchange rate is a function of countries' relative price of non-traded goods. The relative price of nontradables in each country is given by

$$
\begin{aligned}
p_N^k &= \lambda_N^k - \lambda_T \\
&= (1-\gamma-\alpha)(\tau c_T^k + (1-\tau) y_N^k) + \log(1-\tau) + (\alpha-1) y_N^k \\
&\quad -(1-\gamma-\alpha)(\tau c_T^k + (1-\tau) y_N^k) - \log\tau - (\alpha-1) c_T^k \\
&= (\alpha-1)\left(y_N^k - c_T^k\right) + \log\left(\frac{1-\tau}{\tau}\right) \\
&= (\alpha-1) y_N^k - (\alpha-1)\left(\overline{y_T} + \left(\frac{\left(\gamma - \left(\frac{1}{1-\alpha}\right)^{-1}\right)(1-\tau)}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right)\left(\overline{y_N} - y_N^k\right)\right) + \log\left(\frac{1-\tau}{\tau}\right) \\
&= (1-\alpha)\overline{y_T} + \left(\frac{\left(\gamma - \left(\frac{1}{1-\alpha}\right)^{-1}\right)(1-\tau)}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right)(1-\alpha)(\bar{y}_N) \\
&\quad + \left((\alpha-1)\left(\frac{\left(\gamma - \left(\frac{1}{1-\alpha}\right)^{-1}\right)(1-\tau)}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right) + (\alpha-1)\right) y_N^k + \log\left(\frac{1-\tau}{\tau}\right) \\
&= (1-\alpha)\overline{y_T} + \left(\frac{\left(\gamma - \left(\frac{1}{1-\alpha}\right)^{-1}\right)(1-\tau)}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right)(1-\alpha)(\bar{y}_N) + \left(\frac{(\alpha-1)\gamma}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right) y_N^k + \log\left(\frac{1-\tau}{\tau}\right) \\
&= (1-\alpha)\overline{y_T} + \left(\frac{\left(\gamma - \left(\frac{1}{1-\alpha}\right)^{-1}\right)(1-\tau)}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right)(1-\alpha)(\bar{y}_N) - \left(\frac{\left(\frac{1}{1-\alpha}\right)^{-1}\gamma}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right) y_N^k + \log\left(\frac{1-\tau}{\tau}\right)
\end{aligned}
$$

Using this, the real exchange rate between countries i and j is determined by their relative endowment of the nontraded good only:

$$
rer^{j,i} = (1-\tau)\left(\frac{\left(\frac{1}{1-\alpha}\right)^{-1}\gamma}{\left(\frac{1}{1-\alpha}\right)^{-1}(1-\tau)+\tau\gamma}\right)\left(y_N^j - y_N^i\right)
$$

Countries with low local endowment have strong real exchange rates, that is, a lot of purchasing power. Taking first differences:

$$
\Delta rer_t^{j,i} = \text{const} \times \left(\Delta y_{N,t}^j - \Delta y_{N,t}^i\right)
$$

Countries j with relatively low growth of local endowment have falling (appreciating) real exchange rates.

Curriculum vitae

Personal details	Rahel Studer from Oberentfelden, Switzerland born on 13 March 1980 in Aarau, Switzerland

Education

September 2010 – October 2016	Doctoral program at the University of Zurich, Department of Economics
September 2008 – October 2011	Master of Science at the University of Zurich in Economics and Business Administration, Economics
September 2006 – October 2008	Bachelor of Arts at the University of Zurich in Economics and Business Administration, Economics
September 2005 – August 2006	Assessment level year at the University of St. Gallen, Economics and Business Administration
September 2000 – August 2004	Diplom für Real- und Sekundarlehrpersonen, University of Applied Sciences and Arts, Northwestern Switzerland

Professional experience

Since July 2009	Research and Teaching assistent at the Chair for International Trade and Finance, University of Zurich
August 2007 – July 2009	Research assistant at the Chair for Industrial Organization and Environmental Economics, University of Zurich
August 2003 – July 2005	Klassenlehrerin, Sekundarschule Oberentfelden
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